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MOTIVE POWERS

MOTIVE POWERS

AND THEIR PRACTICAL SELECTION

BY

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SECTION I.

CHAPTER I.

INTRODUCTORY.

I AM frequently consulted on the question of the selection of a motive power suited to certain conditions, which conditions frequently vary so greatly that one cannot wonder at the perplexity they produce in the minds of those who are perhaps unacquainted with even the simpler technicalities connected with such matters. The facts, formulæ, and data resulting from experience with machinery, are scattered through books of all kinds, which are inaccessible to some, unknown to others, and, in any case, are so ill-arranged and often over-elaborated as to make them worse than useless to the uninformed.

While the settlement under very difficult conditions of the best motive power to be adopted, remains undoubtedly a matter in which the experience of an engineer is most properly applied, it has appeared to me that a compilation, or a condensation, of the facts that go to settle these questions in the hands of an expert, would prove of wide value not only to his class, but may be made sufficiently simple to be of practical use in those numerous cases where these questions have to be solved by those on the spot without technical aid.

I have aimed, therefore, in the following pages, at the double purpose of condensing and arranging these facts and figures for the easy reference of engineers, and for the

ready comprehension of the non-technical; providing the former, not only with rules and formulæ compactly arranged, but with their results as far as possible worked out for them, and affording to the latter class sufficient direct information, without any but the simplest calculation, to enable them to come to a decision in any case in which the issue is not complicated, or at any rate to be in a position to present their requirements in an intelligent and practical form, either to an engineer for advice, or to a manufacturer for the purpose of estimating. An enormous amount of work, trouble, and anxiety is devoted by the members of my profession to advising and estimating upon requirements ignorantly stated, or in which essential points are ignored, both to the loss of their clients and themselves, and it is, perhaps, not going too far to say that the majority of small motive powers are decided upon, from this cause, in a somewhat hap-hazard manner.

It will be within the knowledge of most mechanical engineers that engines are frequently put to duties for which they are either unsuited, or to which a different system of motive power might have been applied, with economy both in working and in first cost.

Added to the above is a strong need for some practical work dealing with and finally disposing of the system of misdescription which has grown up around the powers of the steam-engine and boiler, and which, in the hands of the unscrupulous, is sometimes made use of to palm off upon the uninformed, machinery of less than proper dimensions. These misnomers and misunderstandings are kept alive by the absence of a direct and simple definition of the essential feature in common of engines and boilers; and this I have in this book not merely formulated, but tabulated, so as to dispose of the last excuse for further use of the misleading term of a "Nominal horse-power." There should be no longer any excuse, with this tabulated information in hand, for any

manufacturer to sell, or for any fairly informed buyer to purchase, engines or boilers defined by nominal powers.

It is really remarkable how many standard text-books and technical hand-books still cling to the use of this term, bolstering up its use by formulæ based upon it, formulæ, that is, which are dependent upon a figure, which as one instructive table in Section IV., Chapter XIX., exhibits, may vary twenty, thirty, even fifty per cent. in value, according to the ideas of liberality or economy of a designer or a manufacturer !

Surely an amazing admission of the personal error into any form of calculation.

An essential feature of this work is the presentation of the cost of the apparatus in each instance. So far as I know it is unique in this matter, which, however, is in nine cases out of ten the guiding or deciding consideration in any comparison. Realizing this it has been my object to present the cost prices all on as uniform a basis as possible, and the figures here given, while necessarily not presenting the lowest prices at which an apparatus might be obtained, are fair figures for a good class of machinery, derived largely from my own purchases and sales in and for many different markets. The essential point about them is, as I have said, that they are fairly on a uniform basis throughout, so that market fluctuations do not greatly affect their value for purposes of comparison one with another. For this reason, and for readier inter-translation, the value of the English pound sterling has been taken at $5.

As I have said, the information relative to the important subject here dealt with is nowhere to be found under one cover, but is scattered over a score or more of hand-books, guides, and even trade catalogues, and the collection of these into a form easy of reference, with the addition of all that my practical experience has brought to my knowledge, has been my task in this work.

In order to facilitate calculation, avoid cross-references, and present a complete view of all considerations of each subject, some repetition of formulæ and data has been resorted to in the different sections.

I have to acknowledge my indebtedness for information to a larger number of works of reference than I could find space to refer to in detail, having endeavoured to exhaust what has been written up to date on each part of my subject, but I desire to record the assistance I have derived from the work and information of the following in particular:

MESSRS. THE BABCOCK & WILCOX COMPANY.
MESSRS. MARSHALL, SONS & COMPANY.
MESSRS. THE WORTHINGTON PUMPING ENGINE COMPANY.
MESSRS. ERNEST SCOTT & MOUNTAIN.
MESSRS. ROBEY & CO.
SIR GUILFORD L. MOLESWORTH.
MR. CHARLES LOUIS HETT.
MESSRS. THE BALL ENGINE COMPANY.

CHAPTER II.

PRIMARY CONSIDERATIONS.

THE first object of a Prime Motive power is to perform a given duty, under given conditions, in the best possible manner.

The secondary object, but, more often than not, that which must perforce take the first place, is that it shall cost less to purchase than any other.

First Cost.—It is evident, then, that not only must the relative duties and economies of one motive power or the other be known, but to arrive at any definite conclusion their relative cost must also be available. For this reason prices of each are included in the succeeding sections. These prices will naturally vary in different localities, but being all on one basis, namely, that of higher class of English and American manufacturers, they afford a parallel of comparison throughout.

To these prices have to be added those of shafting, belts, pulleys, pipes, and sundries, but these apply almost equally to different systems of motive power, and do not, thus, greatly affect the comparison.

Cost of Freight.—In foreign countries, freight and the possibilities of transport often go to make a decision for or against the use of machinery. These important items of cost are arrived at as follows :

Shippers reckon a ton by weight to be equal to forty cubic feet of space occupied, which is called a " ton measurement."

They usually reserve the right to assess freight on goods in whichever way is most profitable to them.

WEIGHT OF CAST-IRON PIPES IN POUNDS PER LINEAL FOOT.

Bore. Ins.	THICKNESS IN INCHES.								
	¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼
1	3.06	5.06	7.36	9.97					
1¼	3.69	5.98	8.59	11.51	14.73				
1½	4.29	6.90	9.82	13.04	16.56	20.4			
1¾	4.91	7.83	11.05	14.57	18.41	22.55	27		
2	5.53	8.75	12.27	16.11	20.25	24.7	29.45	34.46	
2½	6.74	10.58	14.72	19.17	23.92	28.93	34.36	40.03	46.02
3	7.98	12.43	17.18	22.19	27.62	33.29	39.28	45.56	52.16
3½	9.20	14.21	19.64	25.31	31.3	37.58	44.18	51.08	58.29
4	10.44	16.11	22.1	28.38	34.98	41.88	49.09	56.61	64.43
4½	11.66	17.94	24.54	31.44	38.65	46.17	53.99	62.12	70.56
5	12.88	19.78	26.99	34.51	42.33	50.46	58.90	67.64	76.69
5½	14.11	21.63	29.45	37.58	46.02	54.76	63.81	73.17	82.84
6	15.34	23.47	31.91	40.65	49.70	59.06	68.73	78.70	88.75
6½	16.57	25.31	34.36	43.72	53.39	63.36	73.41	84.22	95.10
7	17.79	27.15	36.82	46.79	56.84	67.65	78.53	89.74	101.2
7½	19.03	29	39.05	49.86	60.74	71.95	83.45	95.26	107.4
8	20.02	30.83	41.71	52.92	64.42	76.23	88.35	100.8	113.5
8½	21.69	32.9	44.4	56.21	68.33	80.76	93.49	106.5	119.9
9	22.71	34.52	46.64	59.07	71.8	84.84	98.18	111.8	125.8
9½	23.93	36.36	49.09	62.13	75.47	89.13	103.1	117.4	131.9
10	25.16	38.2	51.54	65.2	79.16	93.42	108	122.9	138.1
10½	26.38	40.04	54	68.26	82.84	97.71	112.9	128.4	144.2
11	27.62	41.88	56.46	71.33	86.52	102	117.8	133.9	150.3
11½	28.84	43.71	58.9	74.39	90.19	106.3	122.7	139.4	156.4
12	30.06	45.55	61.35	77.46	93.6	110.6	127.6	145	162.6

NOTE.—For each Joint add one foot in length of the Pipe.

Heavy iron-work is generally taken at a rate based on *tons weight.* This is the gross weight including packages. Where iron-work is hollow, such as in boilers, pipes, barrels, cylinders, and wheels, or where the machinery is light, as in large cases, the freight is assessed on tons of forty cubic feet. This is on the gross measurement outside to outside of all projections.

A boiler with a dome or chimney will be measured from the top of either. A globe 3′ 6″ diameter would be meas-

ured as 41.12 cubic feet, and would pay freight as over one ton though it weighed but a hundredweight. If made of iron solid it would weigh four and a half tons and pay upon weight.

Pipes are objects which are frequent causes of misunderstanding, as the weight and cubic contents approach in some sizes closely, especially when packed as they should be, so that their projections or flanges miss each other.

Shippers will, however, measure them as square blocks the extreme size of the flanges, unless this is arranged. Their weight may be found on preceding page.

WEIGHT OF A SUPERFICIAL FOOT IN POUNDS, AND NUMBER OF SUPERFICIAL FEET PER TON OF IRON AND STEEL PLATING OF VARIOUS THICKNESSES.

Thickness.			Weight per superficial foot in pounds.		Number of superficial feet per ton.	
Parts of an inch.	Decimals of an inch.	Millimètres.	Iron.	Steel.	Iron.	Steel.
1/16	.0625	1.588	2.5	2.55	896	878.4
1/8	.125	3.175	5	5.1	448	439.2
3/16	.1875	4.762	7.5	7.65	298.7	292.8
1/4	.25	6.35	10	10.2	224	219.6
5/16	.3125	7.937	12.5	12.75	179.2	175.7
3/8	.375	9.525	15	15.3	149.3	146.4
7/16	.4375	11.112	17.5	17.85	128	125.5
1/2	.5	12.7	20	20.4	112	109.8
9/16	.5625	14.287	22.5	22.95	99.6	97.6
5/8	.625	15.875	25	25.5	89.6	87.8
11/16	.6875	17.462	27.5	28.05	81.5	79.9
3/4	.75	19.05	30	30.6	74.6	73.2
13/16	.8125	20.637	32.5	33.15	68.9	67.5
7/8	.875	22.225	35	35.7	64.	62.8
15/16	.9375	23.812	37.5	38.25	59.7	58.6
1	1.0	25.4	40	40.8	56	54.9

1 inch = 25.39954 millimètres.
1 pound = 0.45359 kilogramme.

1 millimètre = 0.03937 inch.
1 kilogramme = 2.20462 pounds.

The following weights will aid calculations.

Weight of Iron.

$\frac{5}{8}$ inch diameter	= 1 lb. per lineal foot run.
$\frac{7}{8}$ inch diameter	= 2 lbs. per lineal foot.
$1\frac{1}{4}$ inch diameter	= 4 lbs. per lineal foot.
$1\frac{3}{4}$ inch diameter	= 8 lbs. per lineal foot.
1 inch square	= 3.33 lbs. per lineal foot, or 10 lbs. per lineal yard.
1 inch thick × 1 foot square	= 40 lbs.
1 inch cube wrought iron	= .28 lb.
1 inch cube cast iron	= .26 lb.
400 cubic inches of wrought iron	= 1 cwt., or 112 lbs.
400 cubic inches of cast iron	= 1 cwt., or 112 lbs.

CHAPTER III.

AVAILABLE POWERS.

Natural Forces.—If the natural elements of light, wind, waterflow, and muscular force could be always relied upon to perform their functions with certainty and regularity, there would be little cause to consider the comparative advantages of adopting any other means of obtaining force.

Although these natural forces are lacking in those important features, there are very often local advantages which modify or outweigh the lack of regular supply, and which should be inquired into before deciding against their use.

These may be classified as follows:

I. In muscular manual force, the cheapness in certain localities of labour, as in the East, whereby it may be brought into competition with machinery.

II. In muscular animal force the cheapness of animals, or their partial requirement for other duties, and availability at other times for power purposes.

III. In the force of the wind, peculiarly favourable situations where a more regular supply may be relied upon.

IV. In the force of water in motion, its ready storage in certain districts.

The relative values and work performed by each of the above are dealt with in succeeding sections.

Nature further provides the means of operating other machinery, by supplying fuels, which form our only alternative means of obtaining motive power by the generation of heat in their destruction by fire.

Fuels.

Coal, or lignite,
Mineral oil,
Natural gas,
Timber or peat,
Straw and reeds,

and a further class of *waste materials* due to processes carried on in a neighbourhood, such as sawdust, cinders, town-refuse, waste gases from furnaces.

Where these exist, or are in any way accessible, their relative prices would be well worth ascertaining, before deciding on the use of one or the other.

Cost of Water.—This matter has an important bearing upon the question of the use of several forms of prime motors. Water is required for boilers, but may be condensed and thus used over again. It is, however, necessary to have a supply or reserve for the process of condensation. It is required by gas and petroleum engines to keep the cylinders cool, though in less quantity.

In fact, some water may be considered a necessity in all the heat engines, though, naturally not in the same volume as when utilized to provide force by its own fall.

Comparative Summary.—A summary of the relative values or costs of these natural forces, which are dealt with more fully under their separate sections hereafter, is rather instructive reading, and for a ready estimation, presents the matter in a practical form within a few lines.

The effect of one effective horse-power, of 33,000 pounds raised 1 foot high in a minute, is to be obtained in the following manners :

By men—	By 12 men working cranks.
By animals—	By 3 powerful oxen.
	By 2 good horses.
By wind—	By a 16 ft. windmill in a good breeze.

By water—	By a fall of water of 533 cubic feet or 3,300 imperial gallons falling a foot in one minute.
	By a fall of water of 53 cubic feet or 330 imperial gallons falling 10 feet in a minute.
By fuels—	By $\frac{1}{20}$th of a lb. of the best coal per minute, in the best class of boiler and engine.
	By $\frac{1}{6}$th of a lb. of ordinary coal per minute, in an ordinary boiler and engine.
	By $\frac{1}{3}$d of a lb. of wood per minute, in a special boiler and ordinary engine.
	By $\frac{1}{2}$ of a lb. of straw per minute, in a special boiler and ordinary engine.
By explosions—	By exploding good city supply gas in a first-class gas-engine at the rate of $\frac{1}{3}$d of a cubic foot per minute.
	By exploding good city supply gas in an ordinary gas-engine at the rate of $\frac{1}{2}$ of a cubic foot per minute.
	By exploding petroleum oil at the rate of $\frac{1}{60}$th part of a pint per minute.

It is only necessary, therefore, in order to arrive at a ready approximate conclusion as to the local economy and value of one or other of the above, to multiply any one by the minutes of work in a day, and multiply the result by the number of effective horse-powers required. This will give the total material used. The cost of either will then be reached by a knowledge of its local cost or price.

CHAPTER IV.

QUESTIONS OF ADVISABILITY.

THESE are points where the circumstances of the user outweigh other considerations, and, to them, the engineer is very often obliged to bend his recommendations.

It is impossible to lay down general regulations for the thousand conditions and circumstances which surround any operation, which it would be necessary then to imagine and describe.

One of those old saws that the experience of our forefathers originated to afford guidance in such cases says, that "Where necessity pinches, boldness is prudence." In other words, it recommends us the use of common sense in tackling the difficulty or circumstances fairly, and meeting them armed with modern knowledge, when they may not infrequently be made actually advantageous.

Thus, one of the main difficulties which engineers experience in advising upon this subject lies in the absence of a knowledge of what *might or could be possibly arranged*, in other words, of how conditions can or may be varied.

A man demands a motor to work eight hours per day. Therefore, his water-supply being irregular, he is told he must have a steam-engine. Whereas perhaps he could work his motor for four hours and lay by for two or four hours, when his reservoir would recuperate itself and he could work the other four.

Or a wind-engine is condemned because it cannot be relied upon to work hour after hour with regularity. Whereas the average year's work of such a mill would perhaps be far in excess of the total requirements, and the attend-

ant's time might be profitably employed elsewhere when the mill was idle.

These considerations extend themselves into economic matters. As an instance may be cited the operating of a sugar mill. This may be driven by any motor. Animal power is sufficient for the smallest scale. Wind and water-power would do well, but owing to the need for heat for the evaporating apparatus, steam becomes preferable, and it becomes particularly so, when it is found that the steam may first drive the mill through the engine, and afterward do extra duty in evaporating.

Passing off as low-pressure steam, it nevertheless contains a large part of the heat imparted to it, and the steam-engine becomes a part of a very economical combined apparatus for power and evaporation.

Further inquiry elicits another factor in favour of steam, for there is an immense amount of waste cane, from which the juice has been extracted, which may be made to serve as fuel under the boiler.

On the other hand, there may be cases where the transport of such a large and heavy article as a boiler is out of the question, and its natural advantages be necessarily abandoned in favour of some other power.

Boilers, too, may be prohibited in certain places where danger is to be feared from the presence of a fire, or where premises may be overheated by its use. Oil and gas-power are similarly affected in cases where they might cause damage to sensitive stock.

Insurance and town-surveyors' regulations have sometimes to be closely considered, and vary greatly with locality.

Nuisances are important matters. The smell of oil- or gas-engines and the vibration due to them or to steam-engines may have to be provided against, and can be overcome by proper arrangements.

So, also, may the noise of motive machinery of all kinds,

when properly made and regulated. "Pounding" in engines indicates loose joints and consequent wear. "Knocking" is often due to the carrying over of water in the steam.

Smoke Nuisance.—Smoke is a fruitful cause of trouble, especially with old boilers, but may be almost entirely obliterated by proper arrangements as to the furnace, or by suitably proportioned chimneys. This matter is dealt with more fully in sections on "Fuels" and "Chimneys" respectively.

Questions of Safety and Immunity from Accident.—Of course every mechanism is open to derangement, due to inherent faults or to carelessness in handling or to both combined.

In the case of wind and water engines, there is likely to be little risk to human life, but in them, as in all machinery, the best materials and workmanship should be ensured by dealing with responsible manufacturers, or by employing an engineer to carefully inspect and test the construction. As to carelessness in operating machinery, it is open to question if the best security, in many cases, would not be the employment of a better class of men than the common stoker or driver, even at a higher cost for wages.

The Question of Labour is one that frequently requires serious consideration, while in certain localities it is so abundant and low-priced as almost to compete with mechanical force, it is far different in others. It may thus occur that, owing to the cost of labor or other difficulties connected with the working classes, it may be necessary to discard the advantages of one force in favour of some other that requires little or no skilled attendance.

It is doubtless such considerations as this which have given so great an impetus to the use of gas and oil engines and turbines, all of which require little or no attention when once set to work.

CHAPTER V.

POWER DEFINED AND COMPARED.

THE term "Power" involves not merely a pull, push, or pressure of a given amount, but a distance over which either is exercised for a given period.

Morin established, as a unit of power, the labour of a strong man, which he found to be equal to the lifting of a weight of 50 lbs. to a height of 1 foot in a second. It was to James Watt that we owed the definition of the world-wide term of "a horse-power."

"Mr. Watt made some experiments on the strong horses employed by the brewers in London, and found that a horse of that kind walking at the rate of 2½ miles per hour, could draw 150 lbs. avoirdupois, by means of a rope, passing over a pulley, so as to raise up that weight, with vertical motion, at the rate of 220 feet per minute. This exertion of mechanical power is equal to 33,000 lbs. raised vertically through a space of one foot per minute, and he denominated it a horse-power, to serve for a measure of the power exerted by his steam-engines."

This term has, during its century of use, been subjected to adjectives which have to a great extent misinterpreted it, and render it necessary when speaking of the above definition by Watt, to call it, an effective horse-power.

An EFFECTIVE horse-power, also known as an "Actual," "Brake," or even a "Belt" horse-power, is, therefore, in any engine, equal to the raising of 33,000 lbs. 1 foot high in 1 minute. This effort is called 33,000 foot-pounds.

In any engine or motor this term is applied to the REAL power of the machine, namely, that which is given off at the shaft or the pulley-wheel, and this is naturally less than the work that is done in the cylinder of the engine, which has had to turn round the machine itself.

An INDICATED horse-power is the same measure of work, but it is "indicated," that is, measured or shown by an instrument inside the cylinder, and thus does not show what is available on the shaft or wheel. It is in effect the real power of the expanded steam, or the exploded gas or oil, and of course from it must be deducted the power it takes to push the working parts round, before the real work it represents is ascertained. This deduction may be averaged at fifteen per cent. In the calculations which follow it has been taken at as high as twenty per cent., for the sake of absolute security. The indicated horse-power of an engine is thus a most useful term, because it tells what work is being really accomplished by the expansion of the steam or gas, and further gives us, in the case of steam-engines, a measure of what the boiler is doing, or what it ought to do.

A "COMMERCIAL" horse-power is a term which has been widely used in the United States, since its adoption as a standard of comparison by the judges at the Centennial Exhibition. It represents an amount of 30 pounds of water evaporated from feed water at a heat of 100° F. and raised therefrom to 70 pounds pressure. It is, of course, merely a selection of these figures out of all others, but, as far as it goes, is a reasonably average performance to select, and if it were universally used it would form a fair basis to work upon. Its application is practically suited only to boilers, although by proportionate calculation a parity can be established with steam-engines working under different conditions, but even as regards boilers, as their pressure varies, it becomes for all, except those suited to 70 pounds pressure, a merely theoretical basis.

It does not, therefore, possess sufficient merit as a term to warrant expectation of world-wide adoption, and for engines it will not supersede the effective horse-power, nor for boilers the basis of comparative heating and grate surfaces.

It is, of course, manifest that mere heating surface with-

out regard to its disposition or efficient position, is not a fair means of comparison between different types of boilers, but it nevertheless forms the only reasonable comparison between boilers of the same pattern.

A NOMINAL horse-power is a commercial term to which unfortunately a large number of manufacturers and merchants, especially in Great Britain, still cling, to denote the sizes of their fixed and portable engines, and especially of the latter.

It is a term of no value, nor of any fixed quantity. It is supposed to mean, in some cases, about one-fourth of what an engine will indicate, in other cases about one-third of the same.

The nominal horse-power of a boiler is not the same as that of an engine, in fact, it is a worthless and misleading term, and very doubtful use has frequently been made of it in covering deficiencies in engines and scamping of dimensions. Reference to Chapters XVIII. and XXIII. will make the above remarks quite clear, and afford material for dealing with any use or misuse of this term.

A RATED horse-power is a term only used in America, where it occupies much the same equivocal position as the term "Nominal" and has about the same negative value.

Animal Powers.—The measure of power for machinery being thus established at 30,000 foot-pounds, we can compare with it the following muscular, or animal powers :

Working eight hours per day.	Pounds raised one foot high every minute.
Horse	21,000
Ox	11,000 to 12,000
Mule	10,000
Ass	3,500
Man, extreme work as in rowing	4,000
Man, on a treadmill	3,100
Man, turning a crank	2,600 to 2,750

Thus the work of twelve men at cranks will only equal one effective horse-power.

Electric Powers.—The electricians have been fortunate, in the early stages of the development of their profession, in being able to settle clearly the terms for the definition of electric currents.

Four terms practically cover the ground.

Volt is a term used to define electric *pressure*, and is practically applied to the electric current as pressure per square inch is by engineers to steam. It is also known as electro-motive force; frequently written E. M. F. for convenience, also potential, and is constantly spoken of as tension or "voltage." This interchange of terms is to be regretted. Here we use exclusively the word volt and voltage.

Ampères are the *quantity* of current, and may be compared with the entire quantities used in defining steam or water. It is frequently written "current." As quantity multiplied by pressure gives us in other calculations a definition of power, so ampères multiplied by volts give us

Watts, or volt-ampères, which are practically the foot-pounds by which we define a horse-power. The Watt is an arbitrary quantity of 1 ampère at 1 volt, of which 746 equal a horse-power, and they constitute the means of comparing electric energy with other powers.

The Ohm is the term used to define the resistance of conductors or wires to the passage of electricity. It answers to the friction opposed to liquids passing through a pipe. The standard ohm is the resistance due to a copper wire $\frac{1}{16}$ of an inch diameter $\times$ 129 yards long. As every conductor offers some resistance to the flow of electricity, the larger the wire the less will be its resistance. Similarly the shorter the wire the less will be its resistance. In estimations of power of electric energy, it is always necessary to bear in mind those losses which occur in all mechanism, due to friction, imperfections, and leakage.

Thus, 10 effective horse-power employed to rotate a dynamo will not produce full 10 effective horse-power of electricity, but a less amount, which may safely be taken as eighty per cent., or 8 effective horse-power, and is so taken in the succeeding tables and calculations.

Inversely, 8 horse-power of electricity given out by a dynamo requires more than 8 effective horse-power to produce it.

Similarly, the conduction of the current over a wire involves a certain loss by friction, which must be allowed for, and of which tables are given, rendering elaborate calculation unnecessary.

Then, the supply of a given quantity of electricity, say a number of Watts, to a motor will not result in an exactly corresponding effective horse-power, but an amount less by from 10 to 15 per cent., which, in my tables, I have, for entire security, taken at 20 per-cent.

SECTION II.

CHAPTER VI.

MANUAL POWER.

THE labour of man cannot be relied upon for long spells of heavy work. The estimate of Morin, that a man-power equalled 3,000 lbs. lifted 1 foot high in a minute, is only true of a very muscular specimen of the human race. The extremity of human exertion is developed in the act of rowing; in which art, enthusiasts are proud to claim that every muscle in the body is developed. At such a labour the maximum effort may reach 4,000 lbs. raised 1 foot high in 1 minute, and in the labour of the tread-wheel a man may reach 3,100 foot-pounds for a spell of work; but labour under such conditions is what humanity would decline to avail itself of, and we are reduced in the average hard work of a man to 2,600 to 2,750 lbs. raised 1 foot high in 1 minute. This is the sort of work developed in turning a crank, which is the most convenient form of application of manual power to machinery.

Crank Handles.—Such cranks should be situated on a shaft about 3 feet from ground level, and should be about 16 inches long, or 32 inches diameter of path.

On these a man imparts a constant pressure of about 15 lbs., which for intermittent work may be increased towards 25 lbs.

The speed at which a man will turn a crank is from 26 to 30 revolutions per minute.

Man Labour.—The labour of one man is just equivalent to $\frac{1}{12}$ of 1 effective horse-power. The labour of 12 men is just equivalent to 1 effective horse-power.

The number of men required to lift water to any height, may be found thus,

$$\frac{\text{Gallons} \times 10 \times \text{height in feet}}{2,750} + 11\% = \left\{ \begin{array}{c} \text{number of men} \\ \text{necessary.} \end{array} \right.$$

The 11 per cent. is added to the result of the calculation to cover friction in the pumps and the pipes.

A very good water lifter for human power is the "Noria," which consists of an endless chain provided with buckets. This is turned round by gearing, the buckets as they arrive at surface automatically emptying themselves as they turn over towards their descent.

With these machines men may raise:

One man—1,000 imperial gallons per hour 15 feet high.
Cost of machine being £13—$65.
750 imperial gallons per hour 30 feet high.
Cost of machine being £18—$90.

Two men—1,500 imperial gallons per hour 30 feet high.
Cost of machine being £24—$120.

Useful Data in this Connection.—

1 imperial gallon of water = 0.16 of a cubic foot;
1 " " " " = 10 lbs. weight;
224 " gallons = 1 ton of water = 2,240 lbs.;
275 " " = 1 ton of petroleum;

$$\frac{\text{Gallons per 24 hours}}{9,000} = \text{cubic feet per minute.}$$

For further figures and calculations with reference to water-quantities, see Section III.

Hand-power Gear.—Where human power is exerted to turn machinery, such as circular or band saws, butter machinery, pumps, and lathes, a good heavy fly-wheel should

be provided, which equalizes the irregularities of the movement.

A good size is 5 feet diameter with a weight of about 400 lbs.

Where two cranks are employed, they are best set at right angles to one another.

Human Endurance.—

"The limits of human endurance are practically summed up in the action of the heart, which normally, in the healthy, will beat 106,000 times in the 24 hours, and its work is computed to be equivalent to the raising of 122 tons 1 foot high.

"Under severe stress of labour, such as straining at a crank, working a cycle, or rowing, this heart action is considerably increased, and such labour continuously prosecuted probably puts double the above duty on the heart-action."—*Lancet.*

From these facts will be gathered the limits of the practical application of human power.

Economy.—The economy of employing the same labour in directing the operations of a machine, rather than in actually operating it, may be considered thus:

It is a question of the value of the efforts of the man and machine combined compared with the unaided efforts of the man.

The machine will have to accomplish in his hands more than the bare work he did unaided, otherwise there would be no economy in its employment.

If higher wages have to be paid for the service of directing the machine, the earnings of man and machine combined must be to that extent in excess of a man's labour.

Similarly, if the machine consumes materials in the course of its action, its earnings will have to be to that extent greater.

It is, however, manifest that man-labour must be inferior to machinery directed by man to such a degree as to make the latter more economical wherever there is sufficient work to keep machines regularly and fully employed.

CHAPTER VII.

ANIMAL POWER.

THE power of animals in comparison with machinery is as follows:

1 Machine effective horse-power	=	33,000 ft.-lbs. per min.
A good horse working 8 hrs. per day	=	21,000 " " "
An ox " " " "	=	12,000 " " "
Mule, " " " "	=	10,000 " " "
Ass, " " " "	=	3,500 " " "

Man working a crank, = 2,600 to 2,750 ft.-lbs. per min., or say $\frac{1}{12}$ of a h. p.

In cases where there is not sufficient work to keep a larger motor employed regularly, or where the output of the machinery to be operated is limited, and where animals are available, their power may be very advantageously employed in a number of small operations.

Towing or Hauling.—The speed of a strong draught horse may be taken at 3 miles per hour.

Oxen do not walk more than $1\frac{1}{2}$ miles per hour.

The following table will show animal work done at various speeds of movement.

MAXIMUM POWER OF A HORSE IN TOWING ALONG A CANAL.

Speed in Miles per Hour.	Hours of Work per Day.	Total Load Drawn in Tons.
$2\frac{1}{2}$	$11\frac{1}{2}$	520
3	8	243
$3\frac{1}{2}$	$5\frac{9}{10}$	153
4	$4\frac{1}{2}$	102
5	$2\frac{9}{10}$	52
6	2	30
7	$1\frac{1}{2}$	19
8	$1\frac{1}{8}$	13
9	$\frac{9}{16}$	9
10	$\frac{3}{4}$	$6\frac{1}{2}$

Animal Gears.—The most usual method of applying animal power to the driving of machinery is by means of an apparatus known in the trade as a "horse-gear." This consists of a framing to be placed on the ground, containing a vertical shaft or spindle, on which is mounted a large bevel cog-wheel. The pole to which the animals are to be attached is secured to this spindle, and as it is turned by the animals' rotary walk the bevel-wheel turns, at a correspondingly higher speed, a horizontal pinion, which operates a shaft. This shaft has a flexible joint connected to it, and may be made of any suitable length. As the motion of animals is so slow, it is necessary to have extra multiplying gear added, which increase the speed of the shaft to a proportionate extent. This multiplying gear is usually carried in a separate frame, but new designs are now arranged to carry the whole in the one framing.

Description.	Cost Complete with Multiplying Speed.	Diameter of Driving Wheel.
Pony Gear	£8 = $40	30"
Mule Gear	£11 = $55	33"
Light Horse Gear	£12 = $60	36"
Strong Horse Gear	£13 = $65	42"
Two Horses	£18 = $90	54"
Three Horses	£20 = $100	54"
Four Horses	£31 = $155	66"
One Ox	£14 = $70	36"
Two Oxen	£16 = $80	42"
Three Oxen	£21 = $105	54"
Four Oxen	£34 = $170	66"

Care should be exercised when purchasing animal-gears to see that an arrangement is provided whereby, when the animals stop, the pole stops also. The impetus of the machine will otherwise carry the pole against them and cause an accident by the sudden stoppage of the machinery, or by frightening the animals.

The pulley upon the driven shaft will be proportioned to the speed required by the machine to be driven by it.

Uses of Horse-gears.—By means of these horse-gears a number of machines may be operated by relays of horses or oxen, and they may also be obtained complete with sets of well-pumps.

Small sugar-cane crushing mills, as well as corn or meal mills, can be economically operated. A horse applied to one of these latter will crush upwards of 24 bushels per hour of maize, beans, barley, etc., as used for feeding animals.

Ginger crushers for mineral water manufacturers afford another instance of similar nature. Small grinding mills may be operated by a horse, grinding fine meal from maize, oats, beans, barley, peas, etc., from 4 to 24 bushels per hour, according to the degree of fineness reached.

Cotton-gins and condensers should be provided with one horse for every 20 saws. The output varies from 2 to 4 lbs. per hour for each saw, except in Sarat or small-seed cottons, where 3 lbs. per saw per hour would be a maximum.

A brick machine, consisting of a pug-mill and outlet and a cutting table will produce with one horse about 5,000 bricks per day—or with 2 horses say 8,000 per day.

Small oil-mills are very suitably driven by animal power. With 2 pair of oxen about 16 cwt. to 20 cwt. of seeds may be crushed in 10 hours, allowing 5 hours' continuous work to each pair of animals.

Pumping by Animals.—For water lifting by animal power, the Noria or bucket pump is widely used abroad. For the watering of vineyards and gardens, irrigating fields, and all purposes where the water is only required to be raised a short distance above the ground level, this apparatus is very suitable. The gears are made suitable for from 1 to 8 animals, which may be yoked in pairs, and quite a large quantity of water may be by this means raised to a moderate height.

The following table is arranged to show the animal power required for this purpose.

TABLE OF ANIMAL POWER APPLIED TO LIFTING WATER BY NORIAS.

Giving the Foot-pounds Corresponding to Each Amount of Work.

PER HOUR.	Lifted 20 feet High.	Lifted 30 feet High.	Lifted 40 feet High.	Lifted 50 feet High.	Lifted 60 feet High.	Lifted 70 feet High.	Lifted 80 feet High.
1,000 imperial gallons..	2,080 ft.-lbs. 1 ass.	3,120 ft.-lbs. 1 ass.	4,160 ft.-lbs. 2 asses.	5,200 ft.-lbs. 1 pony.			
2,000 gallons....	4,160 ft.-lbs. 2 asses or 1 pony.	6,240 ft.-lbs. 1 pony.	8,320 ft.-lbs. 1 mule.	10,400 ft.-lbs. 2 mules or 1 ox.	12,480 ft.-lbs. 2 mules or 2 oxen.	14,560 ft.-lbs. 2 mules or 2 strong oxen.	16,640 ft.-lbs. 1 horse or 2 strong oxen.
4,000 gallons....	8,320 ft.-lbs. 2 ponies or 1 mule.	12,480 ft.-lbs. 2 oxen or 2 mules.	16,640 ft.-lbs. 2 oxen or 2 mules.	20,800 ft.-lbs. 1 strong horse.	24,960 ft.-lbs. 2 powerful oxen.	29,120 ft.-lbs. 3 oxen or 2 horses.	33,280 ft.-lbs. 3 powerful oxen or 2 strong horses.
6,000 gallons....	12,480 ft.-lbs. 1 horse or 2 oxen or 2 mules.	18,720 ft.-lbs. 1 horse or 2 mules or 2 oxen.	24,960 ft.-lbs. 3 mules or 2 horses.	31,200 ft.-lbs. 3 oxen or 2 horses.	37.440 ft.-lbs. 4 oxen or 2 horses.	43,680 ft.-lbs. 3 horses or 4 oxen.	49.920 ft.-lbs. 3 strong horses.
8,000 gallons....	16,640 ft.-lbs. 2 oxen or 2 mules.	24.960 ft.-lbs. 3 mules or 2 horses.	33,280 ft.-lbs. 3 oxen or 2 horses.	41,600 ft.-lbs. 3 horses.	49,920 ft.-lbs. 3 horses.	58,240 ft.-lbs. 5 oxen or 3 strong horses.	66,560 ft.-lbs. 4 horses.
12,000 gallons....	24,960 ft.-lbs. 3 mules or 2 horses.	37.440 ft.-lbs. 4 oxen or 2 horses.	51,200 ft.-lbs. 3 horses.	62,400 ft.-lbs. 4 horses.			
18,000 gallons....	37,440 ft.-lbs. 4 oxen or 2 horses.	56,160 ft.-lbs. 5 oxen or 3 horses.	74,880 ft.-lbs. 4 powerful horses.				

1 imperial gallon = 10 lbs. weight. *6.24 gallons = 1 cubic foot.*

For higher lifts regular pumps should be employed, and the following table of the duties that may be obtained thereby can be readily varied.

TABLE OF HIGHER LIFTS OF PUMPING WORK DONE BY ANIMAL POWER, THE ANIMAL WALKING AT THE RATE OF THREE MILES PER HOUR, AND POWER DEVELOPED THROUGH HORSE GEAR ON TO PUMPS OF 9″ STROKE AT 30 REVOLUTIONS PER MINUTE, ALLOWING 11 PER CENT. FOR LOSSES IN PUMPS.

	Bore of Barrels of pumps, 2½″.	Bore of Barrels, 3″.	Bore of Barrels, 3½″.	Bore of Barrels, 4″.
Single barrel pump worked by a strong pony	250 imperial gallons, lifted 234 ft. high.	360 gallons to 165 feet.	490 gallons to height of 120 feet.	640 gallons to 90 feet.
Double barrel pump worked by one pony.	500 gallons, 117 feet.	720 gallons, 82 feet.	980 gallons, 60 feet.	1,280 gallons, 45 feet.
Treble barrel pump worked by one pony.	750 gallons, 78 feet.	1,080 gallons, 55 feet.	1,470 gallons, 40 feet.	1,920 gallons, 30 feet.
Single barrel pump w'rk'd by a strong horse.	250 gallons, 468 feet.	360 gallons, 330 feet.	490 gallons, 240 feet.	640 gallons, 183 feet.
Double barrel pump worked by a strong horse	500 gallons, 234 feet.	720 gallons, 165 feet.	980 gallons, 120 feet.	1,280 gallons, 91 feet.
Treble barrel pump worked by a strong horse	750 gallons, 156 feet.	1,080 gallons. 110 feet.	1,470 gallons, 80 feet.	1,920 gallons, 61 feet.

CHAPTER VIII.

THE POWER OF WIND.

Of all common things, air is the most common. It is free to all without let or price, and its movement, which we call the wind, affords a power, costing nothing for itself, and but a very moderate amount for the necessary mechanism to make use of it.

Constituent Features of Air.—

Air is of unlimited compressibility and elasticity.

Its elastic force is in direct proportion to the space it occupies.

A cubic foot at atmospheric pressure weighs 564.8 grains.

A ton of air, 2,240 lbs., thus equals 27,810 cubic feet.

The atmosphere extends above us some 50 miles, therefore each square inch of earth surface is sustaining a column of air of about that height, which in normal condition is equivalent to a load of 14.7 lbs. This is bearing on each square inch and is known as atmospheric pressure. It is subject to variations ascertainable by the use of a barometer.

Being a fluid, this pressure is exerted by it on all points of access.

Wind.—When in motion the moving mass of air is called wind, and exerts a pressure due to its speed, upon surfaces exposed to it. This pressure is made use of in the sails of vessels for propulsion, and in the angular sails of windmills for obtaining a rotary motion.

A plane surface exposed angularly to the wind pressure receives a motion due to the angle of impact. Being secured to a revolving shaft, it can only move in the rotary direction.

This faculty has been utilized in the familiar windmill, which is an excellent motor, and suited to a great variety of work requiring moderate power and not too great regularity.

The chief drawback of windmills is their unreliability for steady daily work, but this may be successfully dealt with by means detailed further on. Anyone who witnessed at the Chicago Exposition the multiplicity of duties to which the large number of windmills there exhibited were applied could not fail to be impressed with the future possibilities this simple system of power possesses.

Wind Powers.—To find the force of the wind, $P =$ lbs. pressing on each square foot of surface. $V =$ velocity of wind in feet per second.

$$P = 0.002288 \times V^2.$$

If the velocity in *miles per hour* is known, then, calling it "v,"

$$P = .00492\ v^2.$$

For the calculation of the safety of tall structures exposed to wind pressures it is usual to take 56 lbs. per square foot of exposed surface above 100 feet from the ground, and below that 40 or 45 lbs. Where the surface is at an angle to the direction of the wind the force exerted upon it may be found as follows :

$$P = .0023\ V^2 \times \text{the sine of the angle.}$$

The best course to adopt before deciding for or against a windmill is to arrange with a resident to take daily notes of the force and direction of the wind in the locality where it is proposed to erect the apparatus.

Many such data may be gathered from the daily weather reports published by the Meteorological departments of

America and Great Britain, and also by the agents of Lloyds.

The following comparative table will afford ready information on this subject.

Miles per Hour.	Feet per Minute.	Feet per Second.	Corresponding Force in lbs. per Square Foot.	Description of Wind.
1	88	1.47	.005	Hardly perceptible.
2	176	2.93	.020	Just perceptible.
3	264	4.4	.044	
4	352	5.87	.079	Gentle breeze.
5	440	7.33	0.123	
10	880	14.67	0.492	Pleasant, full breeze.
15	1,320	22	1.107	
18	1,584	26.4	1.623	Strong breeze.
20	1,760	29.3	1.968	Brisk gale.
25	2,200	36.6	3.075	
30	2,640	44	4.428	High wind.
35	3,080	51.3	6.027	
40	3,520	58.6	7.872	Very high wind.
45	3,960	66	9.963	
50	4,400	73.3	12.3	Storm.
60	5,280	88	17.712	Great storm.
70	6,160	102.7	24.108	
80	7,040	117.3	31.488	Hurricane.
100	8,800	146.6	49.2	

1 mile = 5,280 feet. Higher extreme pressures in cyclones have been registered.

Locality.—Naturally, as high and moderately exposed a position as is conveniently possible should be selected. The top of any well-built building or of a good barn will do. Where buildings are not available, a wooden, or better still a steel, frame tower may be used. Costs of these are given in the succeeding tables.

Very exposed headlands, where the full force of storms would be felt, should be avoided. The great point is to secure a position where the average prevailing winds will be caught freely.

Proportions of Windmill Sails.—The following rules enable area, speed, and power of windmills to be calculated :

To find the horse-power developed by a windmill:

$V =$ velocity of wind in feet per second ;
$A =$ total area of all the sails in square feet ;

$$\text{Effective horse-power} = \frac{A \times V^3}{1{,}080{,}000}.$$

Modern improved mills give power as follows :

Diameter of Wheel in Feet.	12	13	14	16	18	20	22	24	25	28	30	36	40	50	60
Horse-power with wind at 14 m. per hour	½	⅝	¾	1	1½	1¾	2	2½ to 3	3	4½	5	6	19	15	20
Horse-power with wind at 18 m. per hour	1	2	3	3½	4	4½	5	6	7	8	10	12	18	28	40

Area of Sails.—We next come to the calculation of the proper area of sail to represent a given power.

This area in square feet equals

$$\frac{\text{Horse-power} \times 1{,}080{,}000}{\text{The velocity of the wind in feet per second, cubed,}}$$

or

$$\frac{\text{Horse-power} \times 1{,}080{,}000}{V^3}.$$

Proportions of Sails.—The usual practice in proportioning the standard windmill sails was to adopt a length of whip or arm, which was usually 30 feet, and then proportion the whip and sails as follows :

Length of whip, say 30 feet.
Breadth at axis, " $\frac{1}{30}$ of length.
Depth " " " $\frac{1}{40}$ " "
Breadth at tip, " $\frac{1}{60}$ " "
Depth " " " $\frac{1}{80}$ " "

Width of sail at axis, say $\frac{1}{6}$ of length of whip.
General width of sail, " $\frac{1}{3}$ " "
Distance of the sail from axis, say $\frac{1}{7}$ of length.
Cross-bars should be from 16 to 18 inches apart.

Axis Line.—The axis or centre line of the shaft of the sails should be tipped on level ground 8 degrees from the horizontal. In high, exposed positions, 15 degrees from the horizontal.

The modern windmills have an essential improvement over the old sail-mill, their vanes or sails being made of wood, and designed in such a form that when the wind pressure exceeds an amount of 14 or 18 miles per hour, they commence automatically to "feather," or assume a more acute angle to the direction of the wind, this process continuing with any further increase, until the sails present only an edge to the force of a high storm—which then blows through the structure with a minimum of obstruction.

By this ingenious arrangement, which may be varied at will by hand-gear, windmills become practically self-regulating, and the chief difficulty of their management is quite overcome.

Some designs are made with arrangements to bring the entire wheel edgeways to a storm. These are not to be commended.

The "Halladay" wheel is very ingenious and successful. The vanes, or slats, are arranged so as to present their points or lower edges only, in a storm, to the wind.

The wheel is a skeleton frame-work, into which a series of wooden sections are centred, which vary in number according to the size of the windmill. The sections are connected with the counter-balance weights, which balance them to such a nicety that when the wind presses too heavily on them, as for instance in a storm, the wheel opens, and assumes a tubular form, allowing the wind to pass

freely through it, which stops the windmill. As the pressure decreases the sails tilt back again into their old position, when the windmill recommences work.

Steering.—Small mills are usually steered by a vane or flat plate of wood attached to the rear of the wheel-framing. A better arrangement is a steering paddle wheel, which is proportioned so as to prevent the swaying or "creeping" of the sail face in a wind.

Speed of Windmill Wheels.—To find the velocity of the tips of the vanes, the rule is

2.6 × the velocity of the wind in feet per second = velocity of the tips of the vanes in feet.

Modern wheels run as follows:

Diameter in feet........	10	12	13	14	16	18	20	22	25	28	30
Revolutions per minute..	50	48	46	43	40	37	34	32	30	28	26

Practical Uses.—As now constructed the windmill may be purchased in many commercial sizes, and has been applied to such a number of practical installations as to afford reliable data upon which to rely in deciding on the use of such a motor.

Some of these are detailed as follows:

10-foot wheel, pumping from a well 63 feet deep into a reservoir.

10-foot wheel, pumping from a well 80 feet deep to a distance of 300 yards.

14-foot wheel, pumping from a well 100 feet deep into a reservoir.

16-foot wheel, on a roof 70 feet high, driving a lathe and drilling machine and also pumping from basement to roof.

16-foot wheel, on steel tower 24 feet high, pumping from well 100 feet deep.

18-foot wheel, pumping water 180 foot lift and to 1,000 yards distance.

20-foot wheel, on steel tower 24 feet high, lifting water by a scoop-wheel from 200 acres of marsh land, at 1,000 to 2,000 gallons per minute.

30-foot wheel, 100 feet from ground level, driving two pairs of 4-foot millstones and a friction hoist for sacks. In a day this mill, with one pair of stones, grinds 15 sacks of wheat.

30-foot wheel, driving a pair of 48-inch burr stones, a crushing mill, and a circular saw.

30-foot wheel, on a tower 76 feet high, supplying local waterworks by a set of three-throw 6-inch pumps, lifting the water 150 feet high through ½ mile of mains to reservoir.

30-foot wheel, on top of building of 7 floors, pumping 11,000 gallons per hour to top of building with two 6 inch double-acting pumps, also working grain elevators.

From the above facts it will be sufficiently evident that these machines are applicable to a variety of work, notwithstanding the irregularities of the wind

In arranging for pumping purposes a reservoir should be provided giving at least two days' reserve, or more if conveniently possible.

Electric Work.—For electric lighting purposes, a set of accumulators should be provided, answering the same purpose of a reserve of power, which can be utilized for lighting or for driving a motor.

Such a plant was in successful operation for some time in London until stopped by action taken against the use of the wheel as infringing the law with reference to sky signs.

A description of this will be of interest as a successful record:

The wheel was erected on the roof of the building on substantial timber supports, and was set to drive a dynamo capable of developing a current of about 30 ampères with 70 volts pressure. The windmill drove this at a rate which, taken with the use of the governor and "cut-out" employed, was sufficiently uniform to charge a battery of 28 accumulators. From this battery sufficient electricity was obtained for two and sometimes three 1,500 candle-power arc-lamps and 27 incandescent lamps. The windmill consisted of a sectional wheel with a vane at the back, the whole arrangement being mounted on a turntable. The vane acted as a rudder and kept the wheel always facing the wind. The wheel, which was 30 feet in diameter, consisted of a skeleton framework, into which a series of wooden sections were centred, and these were connected with counterbalance weights which acted as governors, and caused the sections to open and shut, according to the strength of the wind blowing, thus obtaining a comparatively uniform speed. By means of a sliding contact, worked by a governor on the dynamo shaft, the charging circuit of the electrical apparatus was switched on when the speed was high enough, and switched off when it dropped too low, and there was also an automatic switch which reduced the existing current when the speed was too high, and thus prevented too much current being forced into the cells at any time. In addition to this there was a resistance in the main circuit, which aided the automatic excess-switch in its action. The governor controlled a lever which short-circuited and opened up resistances which were arranged in the shunt of the machine, and so regulated the electro-motive force according to speed.

In Chapter XXXV., devoted to electricity and its storage, will be found full particulars and costs of dynamos and accumulators, with their outputs of current and correspond-

ing lamps, and also power for driving motors, but for the sake of ready reference the following are abstracted.

A Set of 26 Accumulator Cells Containing:	Gives Effective Power in a Motor for 10 Hours of:	Operates Lamps.	Cost of Cells.
7 plates each,	.696 effective h. p.	10 of 16 c. p.	£45 = $225
11 " "	1.2 " "	18 of 16 "	£63 = $315
15 " "	1.76 " "	25 of 16 "	£84 = $420
23 " "	2.68 " "	38 of 16 "	£125 = $625
31 " "	3.52 " "	50 of 16 "	£165 = $825
Set of 32 cells containing:			
23 plates each,	4 " "	46 of 16 "	£154 = $770
31 " "	5.30 " "	60 of 16 "	£203 = $1,015
Set of 53 cells containing:			
31 plates each,	7.04 " "	100 of 16 "	£334 = $1,670

Finally, the following practical list will be found useful.

SIZES, POWER, AND COST OF MODERN WINDMILLS.

Diameter of Wheel.	Revolutions per Minute.	Effective Horse-power. Wind at 14 Miles.	Effective Horse-power. Wind at 18 Miles.	Cost of Windmill and Gear Suited for Driving Machinery.	Cost of Windmill Ungeared. Suited for Pumping.	Cost of Steel Tower 24 Feet High.
Feet.		H.-P.	H.-P.			
12	48	$\frac{1}{2}$	1	£25 = $125	£25 = $125	£28 = $140
13	46	$\frac{5}{8}$	2	£30 = $150	£30 = $150	£30 = $150
14	43	$\frac{3}{4}$	3	£50 to £60 / $250 to $300	£55 = $275	£30 = $150
16	40	1	$3\frac{1}{2}$	£65 to £80 / $325 to $400	£65 = $325	£35 = $175
18	37	$1\frac{1}{2}$	4	£85 = $425	£80 = $400	£40 = $200
20	34	$1\frac{3}{4}$ to 2	$4\frac{1}{2}$	£95 to £100 / $475 to $500	£85 = $425	£45 = $225
22	32	2 to $2\frac{1}{2}$	5	£120 = $600	£100 = $500	£45 = $225
24	31	$2\frac{1}{2}$ to 3	6	£140 = $700	£115 = $575	£45 = $225
25	30	3 to 4	7	£170 = $850	£140 = $700	£47 = $235
28	28	$4\frac{1}{2}$	8	£185 = $925	£150 = $750	£47 = $235
30	26	5 to 6	10	£200 = $1,000	£160 = $800	£50 = $250
35	22	6 to 8	11	£250 = $1,250	....	£60 = $300
36	—	8	12	£275 = $1,375		
40	—	9 to 12	18	£325 = $1,625		
50	—	15 to 20	28	£625 = $3,125		
60	—	20 to 30	40	£780 = $3,900		

SECTION III.

CHAPTER IX.

THE POWER OF FALLING WATER.

THE use of falling water as a means of motive power is always worth consideration, wherever it exists with reasonable regularity. This is equally true of the motion due to the stream in rivers, and, to a less degree, to that due to tidal action, which, however, suffers in a special degree from intermittency.

The movement of water may be utilized in a number of different methods, their comparative values for efficient work being as follows, the theoretical or calculated power of the water being, for the purpose of comparison, taken at 1.00.

Water-wheels	Floating mills	.30
	Undershot wheels	.35
	Poncelet undershot wheel	.60
	Breast wheel	.55
	High breast-wheel	.60
	Overshot wheel	.68
Pelton or jet-wheels		.75
Turbines		from .60 to .80
Water pressure engines		.80
Hydraulic Ram raising part of water as a pump		.60

This theoretical or calculated work of the water is ascertained as follows:

$$\frac{\text{Cubic feet per minute} \times 62.4 \times \text{the fall in feet}}{33{,}000} = \left\{ \begin{array}{c}\text{the work}\\ \text{of the}\\ \text{water.}\end{array} \right.$$

Of this result the different machines make more or less effective use as detailed above. So that to get the effective horse-power of any form of wheel, there must be deducted an amount, from 20 to 70 per cent. of the result, according to the motor selected.

EXAMPLE.—15 cubic feet per second falling 28 feet, used in a turbine of 70 per cent. efficiency.

$$15 \times 60 = 900 \text{ cub. ft. per min.} - \frac{900 \times 62.4 \times 28}{33{,}000} =$$
$$47.63 \times .70 = 33.3 \text{ effective horse-power.}$$

Quantity.—To find the actual quantity of water required by any wheel at any given effective horse-power.

$$\frac{\text{The effective horse-power} \times 528.5}{\text{The fall in ft.} \times \text{the percentage of efficiency given above}}$$
$$= \text{actual number of cubic feet necessary.}$$

All the text-books give rules in the misleading form of theoretical results. The above rule makes allowance for the loss of work in the wheel or motor.

Low falls are sometimes stated in pounds pressure per square foot. These are equivalent to heads or falls in feet, as follows:

Head or Fall in Feet.	Lbs. per Square Foot.	Head or Fall in Feet.	Lbs. per Square Foot.
1	62.4	11	686.7
2	124.8	12	749.1
3	187.3	13	811.5
4	249.7	14	873.9
5	312.1	15	936.4
6	374.5	16	998.8
7	437	17	1061.2
8	499.4	18	1123.6
9	561.8	19	1186.1
10	624.2	20	1248.5

See, also, an extended table of pressures in lbs. per square inch at end of this section.

Measurement of Water Supplies.—The following rules and tables are devoted to the subject of measurement of water, both through pipes and in streams, and as these measurements have in many cases to be made by non-technical persons, the methods are fully detailed, and as far as possible the calculations are tabulated. It should be borne in mind that upon the accuracy of these measurements depends the success of installations of water-power, so that care is necessary to record results accurately.

Hydraulic Data.—

One imperial gallon	=	277.274 cubic inches
" "	=	.16 cubic foot
" "	≐	10.00 lbs.
" "	=	4.537 litres
One United States Gallon	=	.83 imperial gallon
" "	=	231 cubic inches
" "	=	8.33 lbs.
" "	=	3.8 litres
One cubic inch of water	=	.03607 lb.
" "	=	.003607 imperial gallon
One cubic foot of water	=	6.23 imperial gallons
" "	=	7.48 U. S. gallons
" "	=	28.375 litres
" "	=	.0283 cubic metre
" "	=	62.35 lbs. at 62°
" "	=	.557 cwt.
" "	=	.028 ton
One lb. of water	=	27.72 cubic inches
" "	=	.10 imperial gallon
" "	=	.4537 kilo
One cwt. of water	=	11.2 imperial gallons
" "	=	1.795 cubic foot

One ton of water	=	35.9 cubic feet
" "	=	224 imperial gallons
" "	=	1,000 litres (approximately)
" "	=	1 cubic metre (approx.)
One litre of water	=	.22 imperial gallon
" "	=	61 cubic inches
" "	=	.0353 cubic foot
One cubic metre of water	=	220 imperial gallons
" "	=	1.308 cubic yards
" "	=	61,028 cubic inches
" "	=	35.31 cubic feet
" "	=	1,000 kilos.
" "	=	1 ton (approximately)
" "	=	1,000 litres
One kilo. of water	=	2.204 lbs.
One atmosphere	=	1.054 kilos. per sq. in.

A column of water 1 ft. high = Pressure of .434 lb. per sq. in.

A pressure of 1 lb. per sq. in. = Column of water 2.31 ft. high.

$$\frac{\text{Imp. gallons in 24 hours}}{9{,}000} = \text{cubic feet per minute}$$

One imperial gallon of petroleum = about 8.2 lbs.

Pressure of Water.—Table of the pressure of water in lbs. per square inch for every foot in height to 270 feet. By this table, from the lbs. pressure per square inch the head in feet is readily obtained, and *vice versa*. By the fol-

lowing table, town pressures may be readily brought to feet of head, and the results ascertained.

Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.
1	0.43	46	19.92	91	39.42	136	58.91	181	78.40	226	97.90
2	0.86	47	20.35	92	39.85	137	59.34	182	78.84	227	98.33
3	1.30	48	20.79	93	40.28	138	59.77	183	79.27	228	98.76
4	1.73	49	21.22	94	40.72	139	60.21	184	79.70	229	99.20
5	2.16	50	21.65	95	41.15	140	60.64	185	80.14	230	99.63
6	2.59	51	22.09	96	41.58	141	61.07	186	80.57	231	100.09
7	3.03	52	22.52	97	42.01	142	61.51	187	81.00	232	100.41
8	3.46	53	22.95	98	42.45	143	61.94	188	81.43	233	100.93
9	3.89	54	23.39	99	42.88	144	62.37	189	81.87	234	101.36
10	4.33	55	23.82	100	43.31	145	62.81	190	82.30	235	101.79
11	4.76	56	24.26	101	43.75	146	63.24	191	82.73	236	102.23
12	5.20	57	24.69	102	44.18	147	63.67	192	83.17	237	102.66
13	5.63	58	25.12	103	44.61	148	64.10	193	83.60	238	103.09
14	6.06	59	25.55	104	45.05	149	64.54	194	84.03	239	103.53
15	6.49	60	25.99	105	45.48	150	64.97	195	84.47	240	103.96
16	6.93	61	26.42	106	45.91	151	65.49	196	84.90	241	104.39
17	7.36	62	26.85	107	46.34	152	65.84	197	85.33	242	104.83
18	7.79	63	27.29	108	46.78	153	66.27	198	85.76	243	105.26
19	8.22	64	27.72	109	47.21	154	66.70	199	86.20	244	105.69
20	8.66	65	28.15	110	47.64	155	67.14	200	86.63	245	106.13
21	9.09	66	28.58	111	48.08	156	67.57	201	87.07	246	106.56
22	9.53	67	29.02	112	48.51	157	68.00	202	87.50	247	106.99
23	9.96	68	29.45	113	48.94	158	68.43	203	87.93	248	107.43
24	10.39	69	29.88	114	49.38	159	68.87	204	88.36	249	107.86
25	10.82	70	30.32	115	49.81	160	69.31	205	88.80	250	108.29
26	11.26	71	30.75	116	50.24	161	69.74	206	89.23	251	108.73
27	11.69	72	31.18	117	50.68	162	70.17	207	89.66	252	109.16
28	12.12	73	31.62	118	51.11	163	70.61	208	90.10	253	109.59
29	12.55	74	32.05	119	51.54	164	71.04	209	90.53	254	110.03
30	12.99	75	32.48	120	51.98	165	71.47	210	90.96	255	110.46
31	13.42	76	32.92	121	52.41	166	71.91	211	91.39	256	110.89
32	13.86	77	33.35	122	52.84	167	72.34	212	91.83	257	111.32
33	14.29	78	33.78	123	53.28	168	72.77	213	92.26	258	111.76
34	14.72	79	34.21	124	53.71	169	73.20	214	92.69	259	112.19
35	15.16	80	34.65	125	54.15	170	73.64	215	93.13	260	112.62
36	15.59	81	35.08	126	54.58	171	74.07	216	93.56	261	113.06
37	16.02	82	35.52	127	55.01	172	74.50	217	93.99	262	113.49
38	16.45	83	35.95	128	55.44	173	74.94	218	94.43	263	113.92
39	16.89	84	36.39	129	55.88	174	75.37	219	94.86	264	114.36
40	17.32	85	36.82	130	56.31	175	75.80	220	95.30	265	114.79
41	17.75	86	37.25	131	56.74	176	76.23	221	95.73	266	115.22
42	18.19	87	37.68	132	57.18	177	76.67	222	96.16	267	115.66
43	18.62	88	38.12	133	57.61	178	77.10	223	96.60	268	116.09
44	19.05	89	38.55	134	58.04	179	77.53	224	97.03	269	116.52
45	19.49	90	39.98	135	58.48	180	77.97	225	97.46	270	116.96

Head in feet × .433 = lbs. per square inch ; and inversely, pounds per square inch × 2.3 = feet of head.

Areas.—Areas of pump plungers or pipes of different diameters, and the gallons displaced in every foot

of travel, or contained in a foot length of pipe, are given below:

Diameter.	Area.	Displacement in Imperial Gallons per Foot of Travel.	Diameter.	Area.	Displacement in Imperial Gallons per Foot of Travel.	Diameter.	Area.	Displacement in Imperial Gallons per Foot of Travel.
⅛	.0122	.0005	7¼	41.28	1.783	18¼	261.5	11.297
¼	.0490	.0021	7½	44.17	1.908	18½	268.8	11.612
⅜	.1104	.0047	7¾	47.17	2.037	18¾	276.1	11.927
½	.1963	.0084	8	50.26	2.171	19	283.5	12.247
⅝	.3068	.0132	8¼	53.45	2.309	19¼	291.0	12.571
¾	.4417	.0190	8½	56.74	2.451	19½	298.6	12.900
⅞	.6013	.0259	8¾	60.13	2.597	19¾	306.3	13.232
1	7854	.0339	9	63.61	2.747	20	314.1	13.569
1⅛	.9940	.0429	9¼	67.20	2.903	20½	330.0	14.256
1¼	1.227	.0530	9½	70.88	3.062	21	346.3	14.960
1⅜	1.484	.0641	9¾	74.66	3.225	21½	363.0	15.681
1½	1.767	.0763	10	78.54	3.393	22	380.1	16.420
1⅝	2.073	.0895	10¼	82.51	3.564	22½	397.6	17.176
1¾	2.405	.1038	10½	86.59	3.740	23	415.4	17.945
1⅞	2.761	.1192	10¾	90.76	3.920	23½	433.7	18.735
2	3.141	.1356	11	95.03	4.105	24	452.3	19.539
2⅛	3.546	.1531	11¼	99.40	4.294	24½	471.4	20.364
2¼	3.970	.1717	11½	103.8	4.484	25	490.8	21.202
2⅜	4.430	.1913	11¾	108.4	4.682	25½	510.7	22.062
2½	4.908	.2120	12	113.0	4.881	26	530.9	22.935
2⅝	5.411	.2337	12¼	117.8	5.088	26½	551.5	23.824
2¾	5.939	.2565	12½	122.7	5.300	27	572.5	24.732
2⅞	6.491	.2804	12¾	127.6	5.512	27½	593.9	25.656
3	7.068	.3053	13	132.7	5.732	28	615.7	26.598
3⅛	7.669	.3313	13¼	137.8	5.952	28½	637.9	27.567
3¼	8.295	.3583	13½	143.1	6.182	29	660.5	28.533
3⅜	8.946	.3864	13¾	148.4	6.410	29½	683.4	29.522
3½	9.621	.4156	14	153.9	6.649	30	706.8	30.533
4⅝	10.32	.4458	14¼	159.4	6.886	31	754.8	32.607
3¾	11.04	.4769	14½	165.1	7.132	32	804.2	34.741
3⅞	11.79	.5193	14¾	170.8	7.388	33	855.3	36.949
4	12.56	.5426	15	176.7	7.633	34	907.9	39.221
4¼	14.18	.6125	15¼	182.6	7.888	35	962.1	41.562
4½	15.90	.6868	15½	188.6	8.147	36	1017.9	43.973
4¾	17.72	.7655	15¾	194.8	8.415	37	1075.2	46.448
5	19.63	.8480	16	201.0	8.683	38	1134.1	48.993
5¼	21.54	.9348	16¼	207.3	8.955	39	1194.6	51.607
5½	23.75	1.026	16½	213.8	9.236	40	1256.6	54.259
5¾	25.96	1.121	16¾	220.3	9.516	41	1320.3	57.037
6	28.27	1.221	17	226.9	8.802	42	1385.4	59.849
6¼	30.67	1.325	17¼	233.7	10.095	43	1452.2	62.735
6½	33.18	1.433	17½	240.5	10.389	44	1520.5	65.686
6¾	35.78	1.545	17¾	247.4	10.687	45	1590.4	68.688
7	38.48	1.662	18	254.4	10.990	46	1661.9	71.794

The above table also answers for cubic contents of pipe. Thus a pipe 10 inches diameter contains 3.393 imperial gallons in a foot length, which result multiplied by 10 gives

lbs. weight of water, or being divided by 6.23 is turned into cubic feet.

Jets.—A table of the delivery of water in jets or fire streams. Giving pressure at nozzle, with quantity and pressure necessary to throw good effective streams various distances through different size nozzles, using 100 feet of ordinary 2½-inch rubber-lined hose and smooth nozzles.

COMPUTED BY J. R. FREEMAN.

Size of Nozzle, ¾ inch.

Pressure at Nozzle, lbs. per sq. in.	40	50	60	70	80	90	100
Imperial Gallons per Minute.........	86	96	105	114	122	129	136
Distance thrown Horizontal, feet.....	44	50	54	58	62	65	68
Distance thrown Vertical, feet	60	67	72	76	79	81	83

Size of Nozzle, ⅞ inch.

Pressure at Nozzle, lbs. per sq. in.	40	50	60	70	80	90	100
Imperial Gallons per Minute.	118	132	144	156	167	177	186
Distance thrown Horizontal, feet.....	49	55	61	66	70	74	76
Distance thrown Vertical, feet........	62	71	77	81	85	88	90

Size of Nozzle, 1 inch.

Pressure at Nozzle, lbs. per sq. in.	40	50	60	70	80	90	100
Imperial Gallons per Minute.........	154	173	189	204	218	232	245
Distance thrown Horizontal, feet.....	55	61	67	72	76	80	83
Distance thrown Vertical, feet........	64	73	79	85	89	92	96

Size of Nozzle, $1\frac{1}{8}$ inches.

Pressure at Nozzle, lbs. per sq. in.	40	50	60	70	80	90	100
Imperial Gallons per Minute.........	197	221	241	260	279	295	312
Distance thrown Horizontal, feet.....	59	66	72	77	81	85	89
Distance thrown Vertical, feet........	65	75	83	88	92	96	99

Size of Nozzle, $1\frac{1}{4}$ inches.

Pressure at Nozzle, lbs. per sq. in.	40	50	60	70	80	90	100
Imperial Gallons per Minute.........	246	275	301	325	348	368	388
Distance thrown Horizontal, feet.....	63	70	76	81	85	90	93
Distance thrown Vertical, feet........	67	77	85	91	95	99	101

Size of Nozzle, $1\frac{3}{8}$ inches.

Pressure at Nozzle, lbs. per sq. in.	40	50	60	70	80	90	100
Imperial Gallons per Minute.........	301	337	369	398	426	452	476
Distance thrown Horizontal, feet.....	66	73	79	84	88	92	96
Distance thrown Vertical, feet........	69	79	87	92	97	100	103

N. B.—The above pressures are based on the supposition that the hose is coupled direct to the stream flowing; if, however, the hose is coupled to a long pipe, then an allowance must be made of an amount equal to *friction loss*. See succeeding table of losses by friction.

The pressures given are *indicated* pressures, not effective pressures. Effective pressures would be slightly greater.

The distances given are for *effective* fire *streams* adapted for fire purposes, and are not for mere isolated drops.

Discharge.—A table of the cubic feet discharged through an ordinary orifice, not like a fire-jet or what is technically known as a "vena-contracta," but such as a mill-gate or shuttle, under a direct head of water immediately above it. The following amounts are 64 per cent. of the theoretical,

and are correct for all parallel openings, such as those cut in planks, mill-races, etc.

Head above the Orifice in Feet.	Cu. Ft. Discharged by *One Sq. In. of Orifice* per Minute.	Head above the Orifice in Feet	Cu. Ft. Discharged by *One Sq. In. of Orifice* per Minute.
1	2.137	21	9.798
2	3.027	22	10.022
3	3.699	23	10.252
4	4.275	24	10.470
5	4.780	25	10.694
6	5.235	26	10.905
7	5.657	27	11.110
8	6.048	28	11.315
9	6.412	29	11.507
10	6.764	30	11.712
11	7.091	31	11.904
12	7.404	32	12.096
13	7.712	33	12.288
14	7.993	34	12.467
15	8.281	35	12.646
16	8.550	36	12.832
17	8.812	37	12.911
18	9.075	38	13.184
19	9.324	39	13.356
20	9.561	40	13.523

The Measurement of a Water Supply Derived from Pipes.—In estimating the results to be derived from a town supply it is not sufficient to take into account merely the known head or fall of the system, as the loss due to friction in the pipes is a considerable item to be deducted, and is very greatly increased by bends or turns in the pipes or by restriction in size at any part of the passage. An immense amount of calculation has been devoted to the settlement of the results of water flowing in pipes.

In the case of a town supply it is naturally very difficult for a consumer to ascertain the real conditions under which his supply reaches him, and he can reach a conclusion best by measuring the amount delivered at his tap in a given period, and then by attaching a pressure-gauge by means of a temporary joint he may ascertain the pressure. From 10 to 12 feet of head is absorbed in friction per mile of pipe.

TABLE OF THE LOSSES BY FRICTION IN PIPES. FRICTION LOSS IN LBS. PRESSURE PER SQUARE INCH FOR EACH 100 FEET IN LENGTH OF CAST-IRON PIPE DISCHARGING THE STATED QUANTITIES PER MINUTE. COMPUTED BY G. A. ELLIS, C.E.

Discharge. Imperial Gallons.	SIZES OF PIPES, INSIDE DIAMETER—INCHES.															Discharge, U. S. Gallons.
	¾	1	1¼	1½	2	2½	3	4	6	8	10	12	14	16	18	
4	3.3	0.84	.31	.12												5
8	13.0	3.16	1.05	.47	.12											10
12	28.7	6.98	2.38	.97	.27											15
16	50.4	12.30	4.07	1.66	.42											20
20	78.	19.	6 40	2.62	.67	.21	.10									25
25		27.5	9.15	3.75	.91	.30	.12									30
29		37.	12.4	5.05	1.26	.42	.14									35
33		48.	16.1	6.52	1.60	.51	.17									40
37			20.2	8.15	2.01	.62	.27									45
41			24.9	10.00	2.44	.81	.35	.09								50
62			56.1	22.40	5.32	1.80	.74	.21								75
83				39.	9.46	3.20	1.31	.33	.05							100
103				48.1	14.9	4.89	1.99	.51	.07							125
124					21.2	7.00	2.85	.69	.10	.02						150
145					28.1	9.46	3.85	.95	.14	.03						175
166					37.5	12.47	5 02	1.22	.17	.05	.01					200
207					47.7	19.66	7.76	1.89	.26	.07	.03					250
249						28.06	11.20	2.66	.37	.09	.04	.005				300
290						33.41	15.20	3.65	.50	.11	.05	.007				350
332						42.96	19.50	4.73	.65	.15	.06	.01				400
373							25.00	6.01	.81	.20	.08	.02				450
415							30.80	7.43	.96	.25	.09	.04	.017	.009	.005	500
621								14.32	2.21	.53	.18	.08	.036	.019	.011	750
830									3.88	.94	.32	.13	.062	.036	.020	1,000
1,037										1.46	.49	.20	.091	.049	.028	1,250
1,245										2.09	.70	.29	.135	.071	.040	1,500
1,450											.95	.38	.181	.095	.054	1,750
1,660											.23	.49	.234	.123	.071	2,000
1,867												.63	.297	.153	.086	2,250
2,075												.77	.362	.188	.107	2,500
2,490												1.11	.515	.267	.150	3,000
2.905													.697	.365	.204	3.500
3.320													.910	.472	.263	4,000
3.735														.593	.333	4.500
4,150														.730	.408	5.000
4,980															.585	6,000

The frictional loss is greatly increased by bends or irregularities in the pipes.

The speed at which the water flows inside a pipe has, as will be inferred from the proportionated losses and quantities in the above table, a directly increasing effect on the loss, and the results, over a considerable range of speed and size of pipes, are given in the succeeding table.

OUTFLOW OR DISCHARGE OF WATER FROM A 100-FOOT LENGTH OF DIFFERENT PIPES, UNDER VARIOUS VELOCITIES, WITH CORRESPONDING FRICTIONAL LOSSES.

Internal Diameter of Pipe, Inches.	At a Speed of 2 Ft. per Second, Requiring a Fall of .062 of a Foot to Produce it.		Speed 3 Ft. per Second, Requiring a Fall of .14.		Speed 4 Ft. per Second, Requiring a Fall of .25.		Speed 5 Ft. per Second, Requiring a Fall of .390.		Speed 6 Ft. per Second, Requiring a Fall of .562.		Speed 7 Ft. per Second, Requiring a Fall of .765.		Internal Diameter of Pipe, Inches.
	Cubic Feet Discharged per Minute.	Feet of Fall Lost in Overcoming Friction.	Cubic Feet per Minute.	Feet of Fall Lost by Friction.	Cubic Feet per Minute.	Feet of Fall Lost by Friction.	Cubic Feet per Minute.	Feet of Fall Lost by Friction.	Cubic Feet per Minute.	Feet of Fall Lost by Friction	Cubic Feet per Minute.	Feet of Fall Lost by Friction.	
3	5.89	.659	8.83	1.35	11.8	2.28	14.7	3.43	17.7	4.78	20.6	6.35	3
4	10.4	.494	15.7	1.02	20.9	1.71	26.2	2.57	24.0	3.59	36.6	4.77	4
5	16.3	.395	24.5	.815	32.7	1.37	40.9	2.05	49.0	2.87	57.2	3.81	5
6	23.5	.329	35.3	.679	47.1	1.14	58.9	1.71	70.7	2.39	82.4	3.18	6
7	32 0	.282	48.1	.582	64.1	.979	80.2	1.47	96.2	2.05	112	2.72	7
8	41.9	.247	62.8	.509	83.7	.856	105	1.28	125	1.79	146	2.38	8
9	53.0	.220	79.5	.453	106	.761	132	1.14	159	1.59	185	2.12	9
10	65.4	.198	98.2	.407	131	.685	163	1.03	196	1.43	229	1.9	10
12	94.2	.165	141	.339	188	.571	235	.857	283	1.19	330	1.59	12
15	147	.132	221	.271	294	.457	368	.685	442	.957	515	1.27	15
16	167	.123	251	.255	335	.428	419	.642	502	.897	586	1.19	16
18	212	.110	318	.226	424	.38	530	.571	636	.798	742	1.06	18
20	262	.099	393	.204	523	.342	654	.514	785	.718	916	.953	20
24	377	.082	565	.17	754	.285	942	.428	1,131	.598	1,319	.794	24
26	442	.076	663	.157	885	.263	1,106	.395	1,327	.552	1,548	.733	26
28	513	.07	770	.145	1,026	.244	1,283	.367	1,539	.513	1,796	.681	28
30	589	.066	883	.136	1,178	.228	1,472	.343	1,767	.478	2,061	.635	30

This is calculated, as is the table on page 46, upon a basis of a length of pipe of 100 feet, convenient for decimal multiplication or division, and from it may be gathered the loss of fall or head in conveying a given quantity of water through a certain pipe, leaving the net outflow or discharge to be expected at the end of the length of pipe.

The Measurement of Streams.

I.—This can be effected by causing the water to pass over an artificial dam or weir: thus, a board sunk level across the stream, well puddled all round, and having a notch  cut out, broad enough and deep enough for all the water to pass through and fall perfectly free on the other side. RULE.—Cube the depth of water flowing through notch, extract square root, multiply by 5, which will give quantity in cubic feet flowing over each foot in width; but it saves time to consult the following

TABLE GIVING THE QUANTITY OF WATER IN CUBIC FEET PER MINUTE PASSING OVER A DAM OR WEIR FOR EVERY INCH OF WIDTH.

Depth of Weir Water....	1 in.	2 in.	3 in.	4 in.	5 in.	6 in.	7 in.	8 in.	9 in.	10 in.	11 in.	12 in.
	0.40	1.14	2.09	3.22	4.51	5.92	7.46	9.12	10.88	12.75	14.71	16.76
Fractions of an inch—¼..	0.56	1.36	2.36	3.53	4.85	6.30	7.87	9.55	11.34	13.23	15.21	17.28
" " ½..	0.74	1.50	2.64	3.85	5.20	6.68	8.28	9.99	11.80	13.72	15.72	17.82
" " ¾..	0.97	1.84	2.93	4.17	5.56	7.07	8.70	10.43	12.27	14.21	16.24	18.35

EXAMPLE.—A weir 36 inches wide and 6½ inches deep. The table gives for 6½ inches 6.68 cubic feet of water per minute; this, if multiplied by 36 inches, will give the total quantity of water (6.68 by 36 = 240.48 cubic feet) per minute passing down the stream. The depth of the water must be taken 2 or 3 feet *up the stream;* there drive in a peg until level with the bottom of the notch, then measure the depth of water flowing over the top of the peg.

The weir must be made with the up-stream side vertical.

The crest should be horizontal and the ends vertical. The edges presented to the current must be sharp; if the up-stream edge be beveled or rounded in any degree the result will not be correct.

The stream must not touch the weir except at the edges. The height of the crest above the tail-water, below the weir, should be equal to one-half the depth of the stream flowing over the weir.

II.—BY DISCHARGE THROUGH ORIFICES.—This is a very useful method of measurement, and is particularly applicable to existing mills. The gate or shuttle is raised to the exact height necessary to pass all the water which is coming down. The width and depth of the opening is then carefully measured and the area calculated in square inches; the head or depth from the centre of the opening to the surface of the water above is also noted. The result obtained is termed so many "inches" of water at such a head.

EXAMPLE.—A shuttle, 4 feet wide, takes the full flow of the stream when raised 2 feet, with the water standing 5 feet above the sill, that is 4 feet above the centre of the opening. The width of the opening, 48 inches, multiplied by its depth, 24 inches, gives an area of 1,152 square inches. The actual discharge under a head of 48 inches, taken from the tables, is 4.27 per square inch. Multiplying 1,152 by 4.27 we obtain 4,919 cubic feet per minute, as the actual discharge.

This plan may also be used for estimating the winter supply of a mill which can only be visited in the dry weather. The miller can generally give the exact height to which the shuttle of the by-pass must be raised to discharge the water during the rainy months.

III.—BY THE VELOCITY OF THE CURRENT AND SECTIONAL AREAS OF THE STREAM.—Select a length of the stream, of say 50 feet, of as nearly a uniform section as possible;

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ascertain the area of the section by multiplying the width by the average depth taken in feet and decimals. The result will be more accurate if sections be taken at each end of the selected length of channel, and at one or more equidistant places between them; the average of these sections being used for the purposes of calculation.

Stakes should be placed on both sides of the stream, to mark the chosen length of 50 feet; and lines stretched across stream a few inches above the water make the observation more accurate.

A float consisting of a cork or piece of wood should be thrown in a few feet above the first line, and the time which it takes in traversing the distance between it and the lower one is carefully noted. To obtain accurate results a succession of floats are employed, and the mean time taken.

The calculation required to reduce these observations will be best illustrated by an example :—

If the section of the stream measures 13 square feet, and the time occupied by the float in travelling the 50 feet is 28 seconds, the section 13 square feet, multiplied by the length 50 feet, would give 650 cubic feet passing in 28 seconds. Multiplying by 60, and dividing by 28, we obtain 1,393 cubic feet (nearly) as the amount per minute. But as the velocity has been measured on the surface of the water in the centre of the stream, this quantity must be reduced by one-eighth to allow for the retarding influence of the sides and bottom. We should then obtain 1,219 cubic feet as the quantity flowing per minute.

In irregular streams it may be necessary to use a short length, say 10 feet, for the purposes of measurement.

It is always desirable that the time should be taken with a chronograph or stop watch.

There is always a perceptible difference between the surface velocity of a stream and its mean velocity.

Let V equal the velocity of the surface in inches per second. Then the mean velocity of the stream equals

$$(V + 0.5) - \sqrt{V}.$$

The mean may be taken in sluggish rivers as about 80 per cent. of the surface velocity.

Velocity at surface in feet per second..................	4	8	12	16	20	24	28	32	36	40	44	48
Mean speed of the whole stream	2.5	5.6	9	12.5	16	19.5	23.2	26.8	30.5	34.1	37.8	41.5

Velocity at surface in feet per second...	52	56	60	64	68	72	76	80	84	88	92	100
Mean speed of the whole stream	45.2	49	52.7	56.5	60.2	64	67.7	71.5	75.3	79.1	82.8	90.5

Obstructions in the Stream should be looked for, as they cause an appreciable increase of surface current, which may prove deceptive.

If $A =$ the sectional area of the river in square feet, and $b =$ the same less the obstruction, and $V =$ the velocity previous to the obstruction, then the velocity resulting from the obstruction will be

$$\frac{1.1 \times A \times V}{b}.$$

And the water will rise over the obstruction to the extent of

$$\frac{V^2}{58.6} + 0.05 \times \frac{A^2}{b} - 1.$$

Necessary Information and particulars required for determining the most appropriate type and size of wheel or turbine to utilize a fall of water.

To enable a manufacturer to determine the most suitable size of wheel or turbine, the following information should be furnished as far as practicable :

The fall from head- to tail-water ; and whether this is liable to be altered by floods.

The quantity of water at command.

Power required, or machinery to be driven.

What motor, if any, has been hitherto used.

Vertical height of the shafting to be driven above or below head-water level.

(*a*) Vertical height of ground at site of mill above or below head-water level.

(*b*) Vertical height of mill floor above or below head-water level.

The speed of the shafting to be driven.

The direction in which the wheel, if it is to be a turbine, is to run, viz.: right hand (with the sun) or left hand (against the sun).

(Right hand turbines are sent by makers when not ordered otherwise.)

Reservoir Capacity, or Storage of Water.—Another important matter in connection with the measurement of small streams is the capacity of the reservoir or dam to hold the water as it accumulates while the wheels are not using it. For instance, suppose the natural flow of the stream to be 600 cubic feet per minute, and the reservoir large enough to hold the water for twelve hours, it will readily be seen that double this amount can be used during the next twelve hours; and this can be readily calculated in making the first survey of a water-power. There are 43,560 square feet in an acre; so there is the same number of cubic feet of water for every one foot of depth.

The loss by evaporation in reservoirs varies greatly with locality, and especially with wind action.

Thus an evaporation in still air of 1 is increased to 4.4 in a fresh breeze and to 8.8 in a strong wind and to 12.4 in a gale.

The average loss from reservoirs exposed to the sun equals in summer $\frac{1}{8}$ to $\frac{1}{4}$ inch per day, and throughout the year from $\frac{1}{16}$ to $\frac{1}{12}$ inch per day.

CHAPTER X.

NOTES ON WATER-WHEELS.

NOTWITHSTANDING the antiquity of the employment of water-wheels, they continue to be serviceable motors under certain conditions. Their simple character, which enables them to be locally constructed, is one strong point in their favour in inaccessible districts, also the fact that they can be very well made entirely of timber where iron is dear or unobtainable.

As their economical effect is low, except in the case of the "overshot" form, they cannot compete for efficiency with a fairly good turbine, but where water is over-abundant that may not prove a serious consideration.

The relative advantages of each form of water-wheel are dealt with in succeeding sections; and as regards their general requirements, it may be said at once that these are of the simplest character. The wheel may be located at any point to which the water can be led. Wheels have been constructed up to 60 feet diameter, but they cannot, in large diameters, compete in point of first cost with a turbine, which, for a given power, decreases in first cost as the height of fall increases. To the cost of any turbine, must, however, be added that of pipes to convey water to it, and therefore the proportions of these have to be decided to arrive at a fair comparison.

The more free the access of the water to, and the egress from, a water-wheel, the better; therefore careful attention should be given to proportions in ascertaining the dimensions of flumes or water races. The rule is very simple.

For every 85 cubic feet used by a wheel per minute, allow an area of one square foot in the race.

If tubes are used their area will be found as follows:

Diameter	6″	9″	10″	12″	15″	18″	21″
Area in square feet	.196	.441	.545	.785	1.22	1.76	2.47
Area in square inches	28.27	63.61	78.54	113.09	176.71	254.46	346.36

Diameter	24″	27″	30″	36″	42″	48″	60″
Area in square feet	3.14	3.97	4.90	7.069	9.62	12.57	19.64
Area in square inches	452.39	572.55	706.86	1017	1385	1809	2827

Cast-iron Pipes.—These pipes may be made of cast iron, which is the most usual material, or of riveted plates of wrought iron or steel, the latter being the lightest in proportion to strength.

The weight of pipes will be readily found from the tables below when their thickness is known.

Average tenacity of cast iron used for pipes, 18,500 lbs. per square inch. Taking the factor of safety at $3\frac{1}{3}$, the highest safe tension is 5,500 lbs. per square inch. Allowance must, however, be made for irregular thickness of pipes, stresses due to hydraulic shock, bending stress from pressure of earth above or settlement of earth below the pipes. For these three times the actual pressure should be calculated for, thus giving for factor of safety, $3\frac{1}{3} \times 3 = 10$; and the greatest safe stress due to actual pressure in the pipe = 1,850 lbs. per square inch.

To find the proper thickness of cast-iron pipes, the diameter being previously ascertained,

Let H = the head of water in feet,
or Let P = the pressure in lbs. per square inch,
D = the internal diameter in inches.

Then for pipes less than 12 inches in diameter:

$$\text{the thickness} = 0.000054 \times H \times (D + .37)$$
$$\text{or} \quad = .000125 \times P \times (D + .37).$$

For pipes from 12″ to 30″ diameter:

$$\text{the thickness} = 0.000054 \times H \times (D + .5)$$
$$\text{or} \quad = .000125 \times P \times (D + .5).$$

For pipes from 30″ to 50″ diameter:

$$\text{the thickness} = 0.000054 \times H \times (D + .6)$$
$$\text{or} \quad = .000125 \times P \times (D + .6).$$

Steel Pipes.—For wrought iron and steel pipes a much less thickness suffices, first on account of the superior strength of the material, and secondly because they have not to be cast in moulds with risk of flaws or blowholes, rendering extra thickness a necessity.

D = internal diameter in inches.
P = pressure in lbs. per square inch.

Then the thickness of metal in inches =

$$\frac{D \times P}{11,760} + 0.2.$$

The thicknesses being thus decided, the weights may be gathered from the following tables.

Weight and Cost of Cast-Iron Pipes.—

For each joint add one foot to length of pipe.

The cost of cast-iron pipes varies with locality, and especially with the cost of shipment, for which see Chapter II. They may be safely taken at about \$32 or £6 10*s*. a ton

average, on board ship in American, British, Belgian, or French ports.

WEIGHT OF A FOOT OF CAST-IRON PIPE.

Diameter, Inches.	Thicknesses.							
	1/4"	3/8"	1/2"	5/8"	3/4"	7/8"	1"	1 1/4"
2	5.5	8.7	21.3	16.1	20.3	24.7	29.5	39
3	7.9	12.4	17.2	22.2	27.6	32.3	39.3	52.2
4	10.4	16.1	22.1	28.4	35.0	41.9	49.1	64
5	12.9	19.8	27.0	34.5	42.3	50.5	59.9	76.7
6	15.3	23.5	31.9	40.7	49.7	59.1	68.7	89
7	17.8	27.2	36.9	46.8	57.1	67.7	78.5	101
8	20.3	30.8	41.7	52.9	64.4	76.2	88.4	114
9	22.7	34.5	46.6	59.1	71.8	84.8	98.2	126
10	25.2	38.2	51.5	65.2	79.2	93.4	108	138
12	30.1	45.6	61.4	77.5	93.7	111	128	163
15	37.4	56.6	76.1	95.9	116	136	157	199
16	—	—	—	102	123	145	167	212
20	—	—	101	127	153	179	206	261
24	—	—	120	151	182	212	245	310
30	—	—	150	188	227	266	305	384

Wrought Iron and Steel Pipes.—

The following costs are subject to market fluctuations :

WEIGHT PER LINEAL FOOT AND APPROXIMATE PRICES PER TON, FOR WROUGHT-IRON RIVETED PIPES.

Thickness.	8 in. Diam.	9 in. Diam.	12 in. Diam.	15 in. Diam.	18 in. Diam.
inch.	lbs.	lbs.	lbs.	lbs.	lbs.
1/8	13	14	19	23	28
3/16	20	22	29	34	41
1/4	27	30	38	46	55
5/16	—	—	48	59	70
3/8	—	—	58	71	84

inch.	£ s. d. $	£ s. d. $	£ s. d. $	£ s. d. $	£ s. d. $
1/8	24 0 0 = 120	24 0 0 = 120	24 0 0 = 120	23 0 0 = 115	22 13 4=113.30
3/16	22 0 0 = 110	22 0 0 = 110	22 0 0 = 110	20 0 0 = 100	19 0 0=95
1/4	19 6 8 = 96.60	19 6 8 = 96.60	19 6 8 = 96.60	18 13 4 =93.30	17 13 4=88.30
5/16	—	—	—	—	17 0 0=85
3/8	—	—	—	—	16 13 4=83.30

Thickness.	24 in. Diam.	30 in. Diam.	36 in. Diam.	42 in. Diam.	48 in. Diam.
inch.	lbs.	lbs.	lbs.	lbs.	lbs.
1/8	36	44	53	61	70
3/16	54	66	79	92	104
1/4	72	89	105	122	139
5/16	91	112	133	153	161
3/8	109	134	159	184	209

inch.	£ s. d. $	£ s. d. $	£ s. d. $	£ s. d. $	£ s. d. $
1/8	22 0 0 = 110	21 6 8=106.60	20 13 4=103.30	20 0 0=100	19 6 8=96.60
3/16	18 0 0 = 92.50	18 0 0=90	17 13 4=88.30	17 6 8=86.60	17 0 0=85
1/4	17 6 8 = 86.60	17 0 0=85	16 16 8=84.13	16 13 4=83.30	16 10 0=82.50
5/16	16 13 4 = 83.30	16 13 4=83.30	16 13 4=83.30	16 10 0=82.50	16 6 8=81.60
3/8	16 13 4 = 83.30	16 13 4=83.30	16 13 4=83.30	16 10 0=82.50	16 6 8=81.60

Steel pipes may be purchased as under:

Steel Pipes with Flanges.		Bends of Steel and Cast Iron.	
Diameter of Supply Pipe.	Cost per Foot.	Radius.	Cost Each.
Inches.	£ s. d. $	Ft. In.	£ s. d. $
12	0 15 6 = 3 88	2 3	3 5 6 = 16 37
15	0 19 0 = 4 75	2 3	4 17 6 = 24 37
18	1 3 6 = 5 88	2 6	6 10 0 = 32 50
24	1 8 6 = 7 12	2 9	7 15 0 = 38 75
30	2 6 0 = 11 50	2 9	9 17 6 = 49 37
36	2 15 0 = 13 75	3 0	13 15 0 = 68 75
42	3 7 6 = 16 88	3 0	17 10 0 = 87 50
48	3 17 6 = 19 37	3 6	21 0 0 = 105 00

For high pressures they may be made with spiral seams on a system much in favour in the United States, possessing much greater strength in proportion—as follows, the thickness of sheets being 14 gauge:

Diameter of Pipe in Inches.	8	9	10	12	14	16	18	20	22	24
Working pressure per sq. in., lbs.....	165	150	130	110	95	80	75	65	60	55
Weight per 100 ft. in cwts..	8	9	10	12	14	16	18	20	22	24
Price per foot in shillings.............	6s.6d.	8	10	12	14	16	18	20	22	24
Price per foot in dollars...............	1.62	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00

COST PRICE PER FOOT RUN OF STEEL-RIVETTED PIPES OF VARIOUS THICKNESSES AND DIAMETERS.

Thickness.		Internal Diameter, Inches.								
Wire Gauge.	Inch.	9	10	12	14	16	18	20	22	24
		s. d. $	s. d. $	s. d. $	s. d. $	s. d. $	s. d. $	s. d. $	s. d. $	s. d. $
12	.104	3 10 = 1.96	4 3 = 1.06	5 1 = 1.27						
11	.116	4 4 = 1.08	4 9 = 1.18	5 7 = 1.39	6 6 = 1.62	7 4 = 1.83				
10	.128	4 11 = 1.22	5 4 = 1 33	6 2 = 1.54	7 0 = 1.75	7 10 = 1.95	8 8 = 2.16			
9	.144	5 6 = 1.37	5 11 = 1.47	7 7 = 1.90	7 7 = 1.89	8 5 = 2.10	9 3 = 2.31	10 1 = 2.52		
8	.160				8 4 = 2.08	9 2 = 2.29	10 0 = 2.50	10 10 = 2.70	11 6 = 2.87	11 6 = 2.87
7	.176						10 8 = 2.66	11 6 = 2.87	12 6 = 3.12	13 4 = 3.33
6	.192							12 4 = 3.08	13 6 = 3.37	14 2 = 3.54
5	.208								14 3 = 3.56	15 0 = 3.75
....	3/16	7 6 = 1.88	7 11 = 1.98	8 9 = 2.18	9 7 = 2.39	10 5 = 2.60	11 3 = 2.81			
....	1/4			11 4 = 2.83	12 10 = 3.20	14 3 = 3.56	15 9 = 3.93	17 1 = 4.27	19 0 = 4.75	20 0 = 5.00
....	5/16					17 1 = 4.77	18 9 = 4.68	20 5 = 5.10	22 6 = 5.62	23 9 = 5.93
Cost of each flanged joint with bolts, nuts, and rubber washers.		14 0 = 3.50	18 0 = 4.50	25 0 = 6.25	30 0 = 7.50	36 0 = 9.00	42 0=10.50	48 0=12.00	54 0=13.10	60 0=15.00

TABLE OF PROPER SIZES FOR WOODEN "GRIPES," OR CLAMPS, MADE OF HARD WOOD, OF GOOD QUALITY, WITH SIZES OF THE BOLTS AND THICKNESS OF PLANK FOR DIFFERENT SIZES OF FLUMES AND SPOUTS.

Size of Flume 6 ft. sq., made of Pine Plank 2½ in. thick, Gripes 2 ft. from Centre to Centre.

Heads in Feet.	Size of Gripes with Equal Sides, in Inches.	Size of Gripes with Edge or Narrow Side to the Flume, in Inches.	Size of Gripes with Edge or Narrow Side to the Flume, in Inches.	Size of Bolts in Inches.
5	5½	5×6	4× 6½	9/16
10	6½	6×7	5× 7½	3/4
15	7¾	6×8	5× 8½	15/16
20	7⅞	7×8½	6× 9	1 1/16
25	8½	8×9	7× 9¾	1 3/16
30	9	8×9½	7×10½	1 1/4

Size of Flume 4 ft. sq., made of Pine Plank 2½ in. thick, Gripes 2 ft. from Centre to Centre.

Heads in Feet.	Size of Gripes with Equal Sides, in Inches.	Size of Gripes with Edge or Narrow Side to the Flume, in Inches.	Size of Gripes with Edge or Narrow Side to the Flume, in Inches.	Size of Gripe with Broad Side to the Flume.	Size of Bolts.
5	4	3×4½	2×5½	6×3	7/16
10	4½	4×5½	3×6	7×4	5/8
15	5½	4×6¾	3×7½	7×5	3/4
20	6	5×6¾	3×8½	8×5½	7/8
25	6½	6×6¾	5×7¾	8×5½	15/16
30	6¾	6×7¾	5×8	9×6	1 1/16

Size of Flume 3 ft. sq., made of Pine Plank 2¼ in. thick, Gripes 2 ft. from Centre to Centre.

Heads in Feet.	Size of Gripes with Equal Sides, in Inches.	Size of Gripes with Edge or Narrow Side to the Flume, in Inches.	Size of Gripes with Edge or Narrow Side to the Flume, in Inches.	Size of Gripe with Broad Side to the Flume.	Size of Bolts.
5	3½	3×3[illegible]	2×4	8 ×2	7/16
10	4	3×4¾	2×5½	7 ×3	9/16
15	4½	4×4¾	3×5½	6 ×4	11/16
20	5	4×5[illegible]	3×6½	7½×4	1 3/16
25	5¾	5×5½	4×6½	9½×4	7/8
30	5¾	5×6	4×6¾	7½×5	15/16

Size of Flume 2 ft. sq., made of Pine Plank 2 in. thick, Gripes 18 in. from Centre to Centre.

Heads in Feet.	Size of Gripes with Equal Sides.	Size of Gripes with Edge or Narrow Side to the Flume, in Inches.	Size of Gripe with Broad Side to the Flume.	Size of Bolts.
5	2¼	2×2½	2¾×2	5/16
10	2½	2×3½	5 ×2	7/16
15	3	2×4	7½×2	1/2
20	3¼	3×3¼	4½×3	9/16
25	3½	3×4½	5½×3	5/8
30	4	3×4½	6¾×3	11/16

Coefficient of transverse strength of a hard wood stick 1 ft. long—supported at each end, loaded in the middle—500. Use about one-fifth for safe strain. The sizes of bolts are given large; good quality of iron will be found safe at double this pressure. A stick two-thirds of the size of those in the table will hold while dry; but as they become "water soaked" they lose about one-third their strength. In practice, gripes or clamps smaller than these sizes are put upon flumes, which apparently hold all right until they become wet, when they gradually bend until they have to be removed and replaced by stronger ones. It will appear, at first sight, that the sizes given under 5 and 10 feet head are larger in proportion than those under 30 feet, but when we take into consideration the fact that a small stick will spring or bend more in proportion to its strength than a large one, the sizes will not be found too large for safety.

Flumes Made of Wood.—Water may be conveyed to water-wheels and turbines by wooden flumes or box-pipes of timber, for the proportions of which the preceding table will be found useful.

A highly important detail is the stoppage of drift and rubbish in the water-supply, by means of a grating in the head-race or flume. This may be made of wood or iron.

If of the former, the bars should be about ¾ inch to 1 inch thick and 1 inch apart, and may be about 3 inches wide, with the up-stream side of each beveled to an edge. If of iron make it of ½-inch or ⅝-inch round rods, or flat rods 1½ inch × ¼ inch, about 1 inch apart. Set the whole grating at an angle of say 40 or 45 degrees from the horizontal and bend the upper part to a circle so that the teeth of the rake can pass through in the water-way, and cover over the part of the flume extending from the grating to the wheels.

The rack should be kept clear by raking it free of weeds and rubbish occasionally.

CHAPTER XI.

TIDAL ACTION.

THE natural phenomena of the rise and fall of a tide, due originally to the attractive power of the moon and sun in relative proportions of 2¼ to 1, is complicated by a variety of disturbing circumstances, such as the position of the two bodies mentioned relatively to one another, the parallax of the moon, and the inertia of the mass of water. There are further, the local conditions of contour of the bed, and of the fringe or margin of the ocean, the friction on its bottom and edges, the action of wind, currents, temperature, and barometric pressure.

All these have now been so far discounted by observation and record that it is possible in any given neighbourhood to ascertain the average and maximum tidal motion, and thereby determine the possibility of its use as a motive force.

The available rise and fall is, as already remarked, very greatly affected by local causes, and therefore very little alike in different places. In deep indents of the shore open in the direction of the tidal motion, and of a gradually contracting shape, the convergence of water in motion causes a very great rise and fall. Hence those very high tides of the Bristol Channel, the bays of Fundy and of St. Malo, in which tides up to 60 and even 100 feet rise, are known.

On the contrary, at certain places on the opposite Irish coast the movement is reduced to about 3 feet, though a little distance away it is 12 feet.

In mid-Pacific the range is but 2 to 3 feet, in London it averages 22 feet, at Liverpool 15.5 feet, at Portsmouth 12.5 feet, at Plymouth 12.5 feet, at Bristol 33 feet, while at Southampton, owing to the double inlet round the Isle of Wight, it has a double high tide, first falling 18 inches and then rising again to flood level. Barometric influences have curious effects. At Brest the tide rises 8 inches for a fall of $\frac{1}{2}$ inch in the barometer, at Liverpool 1 inch to $\frac{1}{10}$ of an inch fall, and in London about $\frac{7}{10}$ of an inch to each $\frac{1}{10}$ of an inch fall. So that with a low barometer a high tide may be anticipated, speaking generally.

Naturally, the tide is also disturbed by winds, either accelerating their action or adding to their volume, and *vice versa.*

Estuaries are, by this means, sometimes drained entirely dry, while those in an opposite direction, receiving the force of the wind, are overflooded. From these facts it will be evident that the adaptation of tidal action to power is not so simple as it appears, yet where it exists in a marked degree, it is by no means to be rejected in these days of storage of power. It is, in some measure, the very immensity of the phenomenon that prevents its practical usage.

The destructive action of the waves prevents the construction of buildings for machinery on the margin of the sea, except in protected bays, estuaries, and creeks. But these exist in numbers sufficient to warrant a much wider use in future of this enormous daily energy offered to man by nature.

At Walton-on-the-Naze will be seen a very good example of the use of tide energy. In a protected, almost land-locked estuary, a dam has been run across the channel, impounding at high tide a large acreage of water. The receding tide leaves a gradually increasing fall or drop for this mass of water, which in escaping operates

the wheels of two flour-mills situated at a convenient point.

Wherever the construction of such a dam does not demand too serious an expense, and where nature has provided protection from the direct action of the sea-waves upon the works, such a construction might be advantageously considered.

The result obtainable will be compounded of two factors:

1. The area of water-reservoir to be enclosed and its contents

(acre × 1 foot deep = 43,560 cubic feet.)

2. The mean tidal movement:

It will be obvious that the acreage should be considerably in excess of the total requirements, as the effect of the outflowing water is only equal to a mean of about one-half the total tide-fall.

Practically speaking, unless the acreage impounded is enormously in excess of the turbine or water-wheel's capacity, it would not be advisable to use the water during the fall of the first half of the tide, nor during its final half-rise again, so that the wheel would only be in use during ½ fall and ½ rise of a tide of say 5 hours, plus the slack or low water. The mean fall would then be ¾ of the full fall, and the power obtainable would equal

$$\frac{(\text{Outflow in cubic feet} \times 62) \times (\text{fall of tide in feet} \times .75)}{300 \text{ minutes} \times 33{,}000} \times \text{say } .75 = \text{effective horse-power.}$$

This assumes the use of a turbine or water-wheel giving out 75 per cent. of the power of the water applied through it. The use of tidal movement as a source of power is thus limited practically to 10 hours' work per day of 24 hours,

in two stretches of about 5 hours each (or 300 minutes), at constantly varying periods of the day and night. To employ a number of workmen upon such irregular hours of labour would manifestly be inadvisable, and therefore, except for nearly automatic machinery, mere tidal machinery becomes an impossibility without storage of power.

Its complexion is quite altered, by the aid of electric machinery and accumulators, and its use may not only be made entirely continuous, but its force may be conveyed a convenient distance away from tidal effects.

Practical Possibilities and Results.—From the effective horse-power calculated above, deduct $\frac{1}{5}$ for loss in producing an electric energy, and about 2 per cent. for every 100 yards the current is to be conveyed. From this result deduct a further $\frac{1}{5}$ for losses in reconverting that energy into mechanical work, by means of a motor.

Thus a 10 effective horse-power turbine drives a dynamo, from which a current equal to 8 effective horse-power issues. This current loses by carriage or conveyance over 250 yards to the accumulators a further 5 per cent., leaving at the accumulator 7.6 effective horse-power. By losses in accumulators and in an electric motor we lose a further 20 per cent., leaving a force upon the mill belt of 6.08 effective horse-power.

By a proper arrangement of accumulators such a motor would be able to run continuously 10 hours at a time, the water-mill running two irregular spells of 5 hours each at any part of the day or night.

The relative dynamos, wires, accumulators, and motors will be found fully detailed for driving by this or any other means in the last section of Chapter XXXV. of this book, but for the sake of convenience and clearness, I have tabulated such plants as would be required to make use of water-powers from 6 horse-power upwards.

TABLE OF EXAMPLES OF TIDAL-POWER INSTALLATIONS STORING ELECTRIC ENERGY FOR REGULAR USE.

Mean Fall of the Water, *i.e.*, ½ of the Average Tidal Fall.	Cubic Feet per Hour from the Surface of Reservoir.	Proper Acreage of Reservoir for 5 Hours, 1 Ft. Fall.	Effective H.-P. of Turbine at 75 per cent. Efficiency.	Turbine. Size.	Turbine. Cost.	Dynamo. Size.	Dynamo. Cost.	Accumulators. Number.	Accumulators. Cost.	Motor. Size.	Motor. Cost.	Effective H.-P. given by Motor for 10 Hours.	Effective H.-P. Obtainable for 20 Hours.
4 feet.	49,760	5½ acres.	5 12	20″	£80 $400	3 units.	£50 $250	32 cells of 23 plates.	£153 $765	50 amps. @ 60 volts.	£52 $260	3.194	Half these amounts.
5 "	53,340	6¼ "	7.13	20	£80 $400	4 "	£55 $275	35 cells of 23 plates.	£153 $765	50 amps. @ 65 volts.	£58 $290	4.44	
6 "	58,500	6¾ "	9.38	20	£80 $400	5 "	£60 $300	56 cells of 23 plates.	£254 $1,270	50 amps. @ 105 volts.	£63 $315	5.853	
7 "	63,180	7¼ "	11 80	20	£80 $400	6 "	£70 $350	53 cells of 31 plates.	£336 $1,680	66 amps. @ 100 volts	£73 $365	7.36	
8 "	67,500	8 "	14.43	20	£80 $400	8 "	£90 $450	106 cells of 23 plates.	£508 $2,540	50 amps. @ 180 volts.	£85 $425	9.00	
10 "	60,900	7 "	16.25	17½	£70 $350	10 "	£110 $550	106 cells of 23 plates.	£508 $2,540	50 amps. @ 200 volts.	£95 $475	10.14	
11 "	63,840	7½ "	18.78	17½	£70 $350	10 "	£110 $550	106 cells of 31 plates.	£672 $3,360	66 amps. @ 200 volts.	£115 $575	13.71	
12 "	66,660	8 "	21.40	17½	£70 $350	12 "	£125 $625						
16 "	58,080	6¾ "	24.80	15	£63 $315	15 "	£150 $750						
18 "	61,560	7 "	29.64	15	£63 $315	18 "	£165 $825						
20 "	85,920	10 "	46.00	17½	£70 $350	24 "	£200 $1,000						

Suitable Turbines.—Several types of turbine are suited for these low falls, such as the Victor, the Trent, and especially the Girard, giving a good percentage of effect with water varying in height of fall, but regular in quantity.

The quantity of water required to give one effective horse-power (at 80 per cent. efficiency of wheel) is as follows :

Head in Feet.	1	2	3	4	5	6	7	8	9	10
Cubic feet per minute..	670	330	230	170	132	112	95	83	74	67

Beyond 14 electric horse-power the cost of accumulators so much increases, that an arrangement would be needed to drive the motor direct from the dynamo part of the time, and the balance of the time to drive it by the aid of the accumulators. By this means the accumulators for the smaller powers given above could also be decreased in cost by reducing the number of their plates.

CHAPTER XII.

FLOATING MILLS AND WATER-WHEELS.

THESE machines cannot be said to be of high economy, but still, in cases where a rapid and ample current is always to be relied upon, they are a cheap method of obtaining a given power. An old barge may be converted into a very fair mill with overhanging wheels like a paddle steamer. A better arrangement is to employ two barges stoutly secured together, a proper distance apart, between which the wheel is arranged and revolves. The diameter of such wheels is generally 12 to 15 feet, with 9 to 11 floats 24 to 30 inches deep, and dipping 12 inches in the water. They should be made with curved floats if possible, and the position on the boat should be such that the water has a free entry to the wheel, and no obstacle in getting away from it.

The first thing necessary is to ascertain the speed of the stream.

Stake off a length of 50 feet on both sides of the stream. Station two men, one at each end of the 50 feet chosen. Drop a light float of cork or wood in the stream a few feet above the first stake, and take the time it occupies in passing between the two men. Check this several times for the sake of accuracy.

Let V equal the speed of the stream in feet per second.

Then the velocity of the floats of the wheel in feet per second, which we will call C, will equal .4 of $V = V \times .4$, or $\frac{4}{10}$ of V.

Let A = the dip of the floats in the water.
" B = the width of the floats in the water.

Then the horse-power $= V \times C \times A \times B \times .0028$.

Only very approximate figures could be given as to the cost of a floating mill. Naturally, it would in most cases be unnecessary to construct new floats or barges, and the cost of these would therefore depend greatly on local circumstances. Even a raft might be made to do duty, if timber were plentiful and other craft unobtainable. Their position in mid-stream, in a strong current, does not make them very suitable as motors for the purposes of general industry.

TABLE OF THE PRESSURE OF FRESH WATER AGAINST A PLANE SURFACE AT RIGHT ANGLES TO THE MOTION OF THE WATER.

Velocity in Miles per Hour.	1	2	3	4	5	6	7
Pressure in lbs. per sq. ft. of surface....	3.87	15.49	34.85	61.95	96.80	139.39	189.73

Velocity in Miles per Hour.	8	9	10	12	15	20
Pressure in lbs. per sq. ft. of surface.	247.81	313.63	387.20	557.57	871.20	1548.8

Undershot Water-wheels. — The economy of ordinary undershot water-wheels, having straight paddles or floats, is very low, and Poncelet's improved construction should always be adopted. In this the floats are constructed on a curve bearing a relation to the angle of inflow and depth of same. The result is the raising of the economical use of the water from 35 per cent. to 60 per cent.

The effective power of a Poncelet wheel $= .00113 \times$ the fall $\times$ the quantity of water in cubic feet per minute.

The arrangement of floats should be such as that two are always covering the sluice opening.

The number of floats should equal the diameter of the wheel $\times\ 1.6 + 16$.

These wheels should not be less than 7 feet or more than 16 feet diameter.

An undershot water-wheel 7 feet 6 inches diameter × 3 feet wide will, with two 3-inch pumps, lift about 3,000 gallons an hour 50 feet high, and costs complete with pumps about $400, or £80.

COST OF UNDERSHOT WATER-WHEELS.

Diameter.	Breast, or Width.	Cost.	Specification.
15 ft.	3 feet.	£46 = $230	These costs include: Cast-iron ring in segments; cast-iron centre, bored; cast-iron gudgeon, turned; pitch-pine arms, planed; yellow-pine buckets, pine backing and risers, cast-iron plummer-blocks; cast-iron sole-plates.
20 "	"	£77 = $385	
25 "	"	£115 = $575	
30 "	"	£154 = $770	
35 "	"	£215 = $1,075	
40 "	"	£253 = $1,265	
45 "	"	£297 = $1,485	
50 "	"	£358 = $1,790	
55 "	"	£420 = $2,100	
60 "	"	£495 = $2,475	

Breast and Overshot Water-wheels.—The adoption of one or other of these types of wheels must depend largely on local necessities. There can be no question that where the fall admits of it, the higher the breast adopted, or the nearer the arrangement approaches to that of an overshot wheel, the better the results are likely to be. Well-proportioned wheels of these forms are, however, reliable, and in the case of the overshot type run closely up to the turbine for economy.

The power of either may be found as under:

Let h = the head of water in feet,
Let Q = the quantity of water in cubic feet per minute.

Then
in low breast wheels the effective h. p. = $.00104 \times Q \times h$
in high " " " " " = $.00113 \times Q \times h$
And
in overshot " " " " = $.00128 \times Q \times h$

Inversely, the quantity of water required to provide a given power may be found thus:

$$\text{In low breast wheels } Q = \frac{961 \times P}{h}.$$

$$\text{In high breast wheels } Q = \frac{881 \times P}{h}.$$

$$\text{And in overshot wheels } Q = \frac{777 \times P}{h}.$$

The speed of a wheel may be ascertained by the following table.

Fall of Water in Feet.	5	10	15	20	25	30	35	40	45	50
Velocity of circumference of the wheel in feet per second.	7	6.6	6.2	5.8	5.4	5	4.6	4.2	3.8	3.4

These wheels are usually made from 12 to 50 feet diameter and even larger in exceptional instances, such as the great wheel at Laxey, in the Isle of Man.

Some excellent little pumping water-wheels are manufactured, which may be found very handy for small house and garden supplies, and a list of which, with prices, is therefore appended.

COST OF WATER-WHEELS WITH PUMPS.

Description.	Diameter.	Width.	Price *Complete with* Pump.	Size of Pump.	Water Lifted in 24 Hours.
Overshot.	3 ft.	1 foot.	£27 10 = $137.50	2″	700 gals., 200 ft.
"	"	"	£27 10 = $137.50	2	1,000 " 150 "
"	"	"	£30 = $150	2½	1,500 " 100 "
"	"	"	£35 = $175	Two 2″	2,000 " 50 "
"	6′ 6″	"	£70 = $350	Two 3″	3,000 " 180 "
Undershot.	7′ 6″	3 feet.	£80 = $400	Two 3″	3,000 " 50 "

COST OF ORDINARY MILL WATER-WHEELS.

Description.	Diameter.	Width.	Price *without* Pumps.	Specification.
Overshot, breast.	15 feet.	3 ft.	£46 = $230	These costs include: Cast-iron ring, in segments; cast-iron centre, bored; cast-iron gudgeon, turned; pitch-pine arms, planed; yellow-pine buckets; yellow-pine backing and risers, cast-iron plummer blocks, cast-iron sole plates.
"	20 "	"	£77 = $385	
"	25 "	"	£115 = $575	
"	30 "	"	£154 = $770	
"	35 "	"	£215 = $1,075	
"	40 "	"	£253 = $1,265	
"	45 "	"	£297 = $1,485	
"	50 "	"	£358 = $1,790	
"	55 "	"	£420 = $2,100	
"	60 "	"	£495 = $2,475	

A choice of sizes of overshot water-wheels is afforded from 6 to 40 horse-power, and the following list shows the best wheel to select from 8½ to 32 feet fall:

Effective Horse-power.	With Cubic Feet Water per Minute.	At Head in Feet.	Diameter of Wheel.	Width of Buckets.	Revolutions per Minute.
6	640	8′ 6″	8 feet.	4′ 0″	18.3
6	455	11 0	10 "	3 0	12.3
6	390	13 0	12 "	2 9	10.5
10	800	11 0	10 "	4 6	12.3
10	530	16 0	15 "	3 6	7.9
10	375	21 6	20 "	2 6	5.5
15	775	16 0	15 "	4 6	7.9
15	590	21 6	20 "	3 6	5.5
15	500	26 9	25 "	3 0	4.4
20	750	21 6	20 "	4 6	5.5
20	550	26 9	25 "	3 9	4.4
20	520	31 9	30 "	3 0	3.1
25	775	26 9	25 "	4 6	4.4
25	640	31 9	30 "	3 9	3.1
30	940	26 9	25 "	5 0	4.4
30	760	31 9	30 "	4 3	3.1
35	1,130	26 9	25 "	5 9	4.6
35	920	31 9	30 "	5 0	3.1
40	1,250	26 9	25 "	6 3	3.1
40	1,030	31 9	30 "	5 6	3.1

As water-wheels run so slowly in comparison with other machinery, it is necessary to place a large spur or belt wheel on the axle to increase the speed of the pinion or small pulley on the shaft of the mill, work-shop, or machine to be driven.

A very usual proportion is 10 to 1. That is, with a wheel running at 7 revolutions per minute, a spur wheel 10 feet diameter on the axle would rotate a pinion 1 foot in diameter at 70 revolutions per minute. Such spur-wheels should preferably have teeth of hard wood inserted into the iron rim, and may then gear into an iron pinion. It is usual to construct the spur round the rim of the wheel at one side, or both. Belt driving at such slow superficial speeds is not advantageous.

CHAPTER XIII.

THE PELTON WHEEL.

SMALL motor-wheels are made on the system of a jet of high-pressure water acting against the buckets of the wheel, the whole being enclosed in a case, and these prove extremely handy for driving small domestic machinery, either from a neighbouring fall, or even from a town supply, if that should afford sufficient pressure.

This may be roughly ascertained by observing the highest point in the nearest tall building to which water is supplied, and estimating the difference between that level and the site of the intended wheel. Every foot of fall is equal to .4335 of a lb. per square inch, so the ascertained height in feet of the supply, multiplied by .4335, gives the resultant pressure.

Such little jet motors are adapted to working under pressures from 20 lbs. to 80 lbs. per square inch, nearly equal to 46 feet and 184 feet respectively.

In these little machines the use of water at the rate of 100 gallons per hour gives the following powers under different pressures :

When Pressure is Equal to	20	30	40	50	60	70	80	Lbs. per square inch.
The brake h.-p. given by the water at the rate of 100 gallons an hour is	$^1/_{50}$	$^1/_{35}$	$^1/_{26}$	$^1/_{20}$	$^1/_{16}$	$^1/_{14}$	$^1/_{12}$	of a brake horse-power.

A very excellent arrangement is that in which the supply is controlled by two or more jets, so that part of the supply can be cut off without contracting the size of the remaining jet.

The following table of commercial sizes, lists of which can be obtained from several manufacturers, may be found useful.

Size of Wheel.	Size of Pipes.		Size of the Jet.	Horse-power According to Opening and Pressures.		
	Supply.	Waste.		20 Lbs.	50 Lbs.	80 Lbs.
6"	$\frac{3}{4}$"	1"	$\frac{1}{16}$"	$\frac{1}{20}$	......	......
7	$\frac{7}{8}$	$1\frac{1}{4}$	$\frac{1}{16}$ to $\frac{1}{8}$	$\frac{1}{16}$	......	......
10	1	$1\frac{1}{2}$	$\frac{1}{8}$ to $\frac{1}{4}$	$\frac{1}{14}$	......	......
11	$1\frac{1}{4}$	$1\frac{3}{4}$	$\frac{1}{8}$ to $\frac{1}{4}$	$\frac{1}{10}$	......	......
12	$1\frac{1}{4}$	$1\frac{3}{4}$	$\frac{1}{8}$ to $\frac{5}{16}$	$\frac{1}{8}$	......	......
14	$1\frac{1}{2}$	2	$\frac{3}{16}$ to $\frac{5}{16}$	$\frac{1}{4}$	$\frac{1}{2}$	1
18	$1\frac{3}{4}$	$2\frac{1}{4}$	$\frac{1}{4}$ to $\frac{3}{8}$	$\frac{1}{2}$	1	2
22	2	$2\frac{1}{2}$	$\frac{5}{16}$ to $\frac{7}{16}$	1	2	3
26	$2\frac{1}{2}$	3	$\frac{3}{8}$ to $\frac{1}{2}$	2	3	4

Small impulse-wheel motors cost from $20 or £4 to $100 or £20, according to size, and one or two makers supply wheels of 30 inches and 45 inches diameter with double buckets at prices of $200 or £40 and $300 or £60 respectively.

They, however, come more properly under the heading of the succeeding subject.

The Pelton Wheel.—This is, to speak correctly, only a water-wheel as regards shape, being more properly described as a motor of the impulse type, receiving its power, like the little wheels described above, from the impact of a jet of high-pressure water.

It may be taken that their special suitability is for situations where a high fall exists, but it may economically be employed down to 20-feet falls. Here, however, it is only its low first cost which will recommend it against a turbine.

The speed at which the Pelton wheel runs may readily be found from the computed table below by dividing the figure given therein by the diameter of the wheel adopted.

OWERS OF SAME FROM ¼ H.-P. TO 250.

A			Revolutions per Minute made by Wheels of Various Sizes, being .475 of the Theoretical Velocity at Different heads.									A
Head or Fall of Water in Feet.			Diameters, Inches.									Head or Fall of Water in Feet.
		320	6	12	18	24	36	48	60	72	96	
20	7	10.30	652	326	217	163	108	81	65	45	40	20
30	o	15.45	799	400	266	200	133	100	80	66	50	30
40	4	20.60	921	461	307	230	153	115	92	77	57	40
50	8	25.75	1,030	515	343	257	172	129	103	86	64	50
60	1	30.9	1,129	564	376	282	188	141	113	94	70	60
70	5	36	1,219	609	406	305	203	153	123	102	76	70
80	9	41.21	1,304	652	434	327	217	160	130	109	81	80
90	2	46.36	1,383	691	461	346	230	173	138	115	86	90
100	6	51.51	1,457	729	486	364	243	182	146	121	91	100
110	9	56.66	1,528	763	509	382	255	191	153	127	95	110
120	3	61.81	1,595	800	532	399	266	200	160	133	100	120
130	7	66.96	1,664	832	554	416	277	208	166	139	104	130
140		72.12	1,731	865	573	431	287	216	172	144	108	140
150	4	77.27	1,785	893	595	446	297	223	178	149	112	150
160	8	82.44	1,844	922	615	461	307	230	184	154	115	160
170	1	87.57	1,900	950	633	475	316	237	190	158	118	170
180	5	92.72	1,952	978	651	489	326	244	196	163	122	180
190		97.87	2,008	1,004	669	502	335	251	201	167	125	190
200	2	103	....	1,030	686	514	343	257	206	171	128	200
220	9	113.33	....	1,080	720	540	360	270	216	180	135	220
250		128.78	....	1,152	768	576	384	288	230	192	144	250
280	1	144.24	....	1,218	812	609	406	305	243	203	152	280
300	9	154.54	....	1,262	841	631	420	315	252	210	157	300
400	5	206.06	....	1,457	971	728	485	364	291	243	182	400
500	1	257.57	....	1,613	1,086	807	543	403	326	271	201	500
		follows: {	$40 £8	$70 £14	$130 £26	$200 £40	$300 £60	$375 £75	$450 £90	$500 £100	$750 £150	

RUL... t by the figure in column B. Result equals area of Vent in sq. in.
ective horse-power at 75 per cent. efficiency.
at different speeds.
in inches.

CHAPTER XIV.

TURBINES.

THESE useful water-wheels, for such they really are, may be divided into three classes, viz.: those through which the flow of water is—

(1) Parallel. (2) Inward. (3) Outward.

In the first the water flows through the turbine in a direction parallel to its rotating axis, acting upon curved inclined blades. The Jonval is the best known form of this type.

In the second the water acts at a tangent upon vanes in the plane of rotation, but from the circumference inward. Of such are those known as centre-vent patterns—the Trent, the "Hercules," the Rodney, the Victor, and many others, such as the New Victor, the Schiell, the Climax, etc., while the Girard is made both in this form and the succeeding.

In the third the water acts tangentially upon vanes in the plane of rotation, as in the inward form; but in this case the water introduced at the centre flows outward to the circumference. The Fourneyron and the Girard are made on this principle.

All these types have their respective merits; all can claim to have done good work under certain circumstances. The most convenient general form is undoubtedly the second, though there are cases where the first and third may be found more advantageous.

Compared with water-wheels turbines have a great advantage in economical working, and especially in their high speed of rotation, by which large gearing is done away with and simple direct driving may be employed.

This is particularly advantageous in electric-dynamo

driving, the speeds of which approximate those of turbines, and may by proper choice of powers and proportions be made equal.

A horizontal turbine may then be employed coupled direct to the shaft of the dynamo. Such installations are numerous and successful. An excellent sample has been driving the electric plant in the Genoa railway terminus for many years past.

We are not here concerned with the actual construction of the turbine, rules for which may be found in Molesworth's Pocket-Book of Engineering Formulæ, and various treatises on that special subject. But we are concerned with the practical question of which is the best turbine to suit given conditions of water-supply. For this purpose we may arrange the special merits of the well-known form of turbines upon the market somewhat as follows :

TYPE OF TURBINE SUGGESTED FOR VARIOUS CONDITIONS.

Fall.	If the Work Demands Full Power all the Time, and the Supply is Full and Constant.	If the Work is Irregular, or the Supply is not Full and Regular.	If Cheapness of First Cost is a Primary Object.
Low falls up to, say, 7 feet.	The Victor, the New Victor.	The Trent, the Little Giant Double Turbine.	Little Giant Double or Waverley.
Falls from 8 feet to 40 feet.	The Victor and New Victor.	Hercules.	
Falls from 20 feet to 50 feet.	The Victor and New Victor, Hercules.	Vortex, Centre-Vent, Climax.	
Falls from 50 feet to 300 feet.	Any of these types.	The Girard.	The Pelton Wheel.

The above dissection must not by any means be taken as conclusive or authoritative, but merely suggestive. If a choice is to lie among the various excellent types of turbines on the American and English markets, and of which some such as the Samson, the Leffel, the Swain, the Houston and the Waverley have not been dealt with in detail, it

must be made on the merits of their manufacture and their actual performances.

Then, too, the claims made by different makers as to their machines' performances and efficiencies are so wide that a whole volume would be needed for their dissection and comparison. It suffices to say that responsible makers of any of these machines will, on being informed of the conditions, offer what their experience has told them to be the best form of turbine to suit the requirements.

Useful Effect.—Performances as high as 88 and 89 per cent. of useful effect have been recorded with a turbine, but an average would not exceed 80 per cent. Therefore, for the purposes of calculation, an average of 75 per cent. of the work in the fall and weight of water is a safe assumption.

As, however, the recorded figures may give strength to this conclusion, I append the record of a test made by Mr. Herschel, engineer to the Holyoke Water Power Company:

Diameter of Wheel.	Head in Feet.	Revolutions per Minute.	Horse-power.	Cubic Feet of Water.	Percentage of Useful Effect.
30 inch.	11.65	144.5	52.54	2,751.87	.8676
"	11.66	147.5	51.96	2,755.09	.8564
"	11.70	142	52.02	2,738	.8614
35 inch.	17.13	147.5	134.09	4,994	.8289
"	17.10	150	134.09	4,981	.8334
"	17.31	151.7	135.68	4,895	.8489
"	17.29	160	133.19	4,806	.8497
"	17.32	147	136.08	4,805	.8491

In the *Turbine Reporter*, Mr. Emerson gives the following record:

Head in Feet.	Revolutions.	Horse-power.	Cubic Feet Water.	Percentage.
18.30	343.5	28.62	977.11	.8473
18.34	323	29.36	973.75	.8705
18.10	321.5	29.22	970.39	.8808

It would therefore appear that the assumed useful effect of 75 per cent. is well within the mark of a good machine, and the power obtainable by a turbine from a given fall and quantity of water will run as follows:

$$\frac{\text{Cubic feet per minute} \times 62.35 \times \text{fall in feet}}{33{,}000} \times .75 =$$

effective horse-power of the turbine.

Upon which basis the following useful table by Mr. Hett is calculated.

Quantity of Water per Horse-power.—The following table shows the quantity of water required for each horse-power, when acting under different falls.

TABLE GIVING THE NUMBER OF CUBIC FEET REQUIRED PER HORSE-POWER PER MINUTE AT 75 PER CENT. EFFICIENCY.

Head in Feet.		1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.
0	...	710	355	237	178	142	118	101	88.8	78.9
10	71	64.5	59.3	54.6	50.8	47.3	44.5	41.7	39.5	37.4
20	35.5	33.8	32.3	30.9	29.6	28.4	27.3	26.3	25.3	24.5
30	23.7	22.9	22.2	21.5	20.9	20.3	19.7	19.2	18.7	18.2
40	17.8	17.3	16.9	16.5	16.1	15.8	15.4	15.1	14.8	14.5
50	14.2	13.9	13.7	13.4	13.1	12.9	12.7	12.5	12.2	12.0
60	11.8	11.6	11.4	11.3	11.1	10.9	10.8	10.6	10.4	10.3
70	10.1	10.0	9.86	9.72	9.59	9.47	9.34	9.22	9.11	8.99
80	8.88	8.77	8.66	8.55	8.45	8.35	8.25	8.15	8.06	7.97
90	7.89	7.80	7.72	7.63	7.55	7.47	7.39	7.32	7.24	7.17

Head in Feet.		10 ft.	20 ft.	30 ft.	40 ft.	50 ft.	60 ft.	70 ft.	80 ft.	90 ft.
100	7.1	6.45	5.73	5.46	5.08	4.73	4.43	4.17	3.95	3.74
200	3.55	3.38	3.23	3.09	2.96	2.84	2.73	2.63	2.53	2.45
300	2.37	2.29	2.22	2.15	2.09	2.03	1.97	1.92	1.87	1.82
400	1.78	1.73	1.69	1.65	1.61	1.58	1.54	1.51	1.48	1.45
500	1.42	1.39	1.37	1.34	1.31	1.29	1.27	1.25	1.22	1.20
600	1.18	1.16	1.14	1.13	1.11	1.09	1.08	1.06	1.04	1.03
700	1.01	1.00	.986	.012	.959	.947	.934	.922	.911	.899
800	.888	.877	.866	.855	.845	.835	.825	.815	.806	.797
900	.788	.780	.772	.763	.755	.747	.739	.732	.724	.717

If any available quantity of water be divided by the cubic feet required per horse-power with a given fall (as ascertained from the table), the quotient will be the horse-power at command. Or conversely: with a given head, any proposed horse-power multiplied by the number of cubic feet required per horse-power (taken from the table), will give the number of cubic feet per minute required to produce the proposed horse-power with that head.

With the foregoing may be usefully compared the following table, taken, it is stated, from actual practice, in which it will be seen that the turbines, under average conditions, give results about 5 per cent. inferior to the foregoing table, *i.e.*, they actually required about 5 per cent. more water to give the horse-power, and thus would be rated at about 70 per cent. efficiency.

EFFECTIVE HORSE-POWERS DEVELOPED BY TURBINES FROM 2½ FEET TO 30 FEET FALLS.

Fall in Feet.	5 H.-P.		10 H.-P.		15 H.-P.		20 H.-P.		30 H.-P.	
	Cub. Ft. per Min.	Revs.	Cub. Ft. per Min.	Revs.	Cub. Ft. per Min.	Revs.	Cub. Ft. per Min.	Revs.	Cub. Ft. per Min.	Revs.
2½	1,500	34	3,000	24	4,500	20	6,000	17	....	....
5	750	81	1,500	57	2,280	47	3,000	41	4,500	33
7½	510	136	1,020	97	1,500	79	1,980	68	3,060	56
10	378	180	756	128	1,140	105	1,500	90	2,280	75
15	252	319	504	226	756	185	1,020	160	1,500	131
20	....	....	378	329	558	273	756	232	1,152	194
25	....	....	....	....	450	358	600	310	900	253
30	....	....	....	....	....	....	504	380	756	310

Fall in Feet.	40 H.-P.		50 H.-P.		60 H.-P.		70 H.-P.		80 H.-P.	
	Cub. Ft. per Min.	Revs.	Cub. Ft. per Min.	Revs.	Cub. Ft. per Min.	Revs.	Cub. Ft. per Min.	Revs.	Cub. Ft. per Min.	Revs.
2½	....	....	....	....	...	....	....	....	....	....
5	6,000	28	7,560	26	....	....	....	....	...	....
7½	4,080	48	5,100	43	6,120	40	7,200	36	8,160	34
10	3,000	64	3,780	58	4,560	53	5,280	48	6,060	48
15	1,980	113	2,520	100	3,060	92	3,600	85	4,020	80
20	1,500	164	1,860	148	2,220	136	2,580	123	3,060	116
25	1,200	220	1,500	196	1,800	179	2,100	166	2,400	155
30	1,020	268	1,260	240	1,500	219	1,800	227	2,040	190

It will be seen that this is a very safe and practical table for the falls dealt with.

For the purpose of further comparison and in order more readily to calculate turbine consumptions under the best conditions, the next table contains the water used in an efficiency of 80 per cent., that is, actually requiring less water to perform a given work. This efficiency has been attained under trials, as previously mentioned.

TABLE OF CUBIC FEET REQUIRED PER MINUTE TO GIVE ONE HORSE-POWER UNDER EFFECTIVE HEADS FROM 1 TO 390 FEET. CALCULATED FOR AN EFFICIENCY OF 80 PER CENT.

Head in Feet.	0	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.
		670	330	230	170	132	112	95	83	74
10	67	61	56	52	48	45	42	39	37	36
20	34	32	30	29	28	27	26	25	24	24
30	23	22	21	20	20	19	19	18	18	17

	0	10 ft.	20 ft.	30 ft.	40 ft.	50 ft.	60 ft.	70 ft.	80 ft.	90 ft.
		67	34	23	17	13.4	11.2	9.5	8.3	7.4
100	6.7	6.1	5.6	5.2	4.8	4.5	4.2	3.9	3.7	3.6
200	3.4	3.2	3.0	2.9	2.8	2.7	2.6	2.5	2.4	2.4
300	2.3	2.2	2.1	2.0	2.0	1.9	1.9	1.8	1.8	1.7

It would certainly almost seem as if the foregoing tables were sufficiently comprehensive, yet such is the immense variety of conditions under which nature supplies and man demands, power, that it is necessary to have access to rules which deal with every variation of power and quantity.

Where head and quantity are known, but not the power :

.079 × quantity of water in cube-feet per *second* × head in feet = effective horse-power at 70 per cent. efficiency.

.0846 × quantity in cube-feet per *second* × head in feet = effective horse-power at 75 per cent. efficiency.

Where the head and power are known, but not the quantity :

$$12.67 \times \frac{\text{horse-power}}{\text{head in feet}} = \text{quantity in cube-feet per } \textit{second};$$

or,

$$760.2 \times \frac{\text{horse-power}}{\text{head in feet}} = \text{quantity in cube-feet per } \textit{minute}.$$

Where quantity and power are known, but not the fall :

$$\frac{528 \times \text{H. P.}}{1{,}056} = \left\{ \begin{array}{l} \text{the theoretical fall in feet to produce the} \\ \quad \text{power ; or,} \end{array} \right.$$

$$\frac{528 \times \text{H. P.}}{792} = \left\{ \begin{array}{l} \text{the proper fall to provide to produce the} \\ \quad \text{power at 75 per cent. efficiency.} \end{array} \right.$$

Bear in mind that an additional allowance of height should be made if the fall is through a long length of pipes.

Size of Turbines.—The next step is the settlement of the size of the turbine that will use up the water and head available.

Now the capacity of turbines of the same diameter, but of different forms of construction, varies considerably. The diameter alone is not sufficient to take as a standard of comparison.

The most convenient standard, and that generally adopted, is the area of an opening capable of discharging the same volume of water as the openings of the turbine do. This area is called the vent of the turbine, and is practically

The discharge area of the turbine, which we might compare to the exhaust port or pipe of an engine.

The discharge for which each square inch of opening is suited varies with the fall (to speak accurately, as the square root of the fall), and it is therefore convenient to have reference to a table giving the various discharges from 3 feet to 1,000, which will be found later on.

Knowing a certain number of cubic feet at a given fall it is easy to divide it by the corresponding discharge per square inch, and the result is the number of square inches of vent requisite in the turbine.

Thus 500 cube feet a minute at 25 feet fall.

The discharge in cubic feet per square inch of opening at 25 feet fall is 16.71.

$$\text{Then } \frac{500}{16.71} = 29.86 \text{ square inches of vent required.}$$

Speed of Turbines.—The velocity at which the circumferential part of a turbine, or in other words, its periphery, runs, is determined also by the fall, and varying again, as the square root. Speed of rotation thus has to be settled from the knowledge of the fall or head. It also varies according to the form of the buckets or vanes, and is thus, except to those who know the construction of the turbine, almost an inaccessible quantity.

The fact is that its variations lay within certain known limits, and that these are from 40 per cent. to 70 per cent. of the theoretical velocity of the periphery.

To find the velocity of the periphery in feet per second

$= 6.6 \sqrt{\text{Head in feet}}$ for turbines with *over* 30 feet fall;

and

$6 \sqrt{\text{Head in feet}}$ for turbines *under* 30 feet fall.

The variation in efficient speed due to different forms of buckets or vanes makes it difficult to establish a rule for the settlement of the most efficient speed of each, and as the depth as well as the diameters of the wheels of different makers vary to a considerable extent, these add further to the difficulty.

Still a good average rule for wheels up to 6 feet diameter is as follows:

$$1.4 \times \sqrt{\frac{1.77 \times \text{quantity}}{\sqrt{\text{head}}}} = \left\{ \begin{array}{l}\text{the diameter of the tur-} \\ \text{bine wheel in feet.}\end{array} \right.$$

Mr. Hett has calculated a table covering all the chief types of turbine, which gives a figure for each form or type against each fall, from 3 feet to 1,000, and by which the speed of any diameter of wheel may be easily ascertained by division. This saves a great amount of calculation.

In this the most efficient speeds of each form have been taken as follows:

Girard Horizontal Shaft	.413
Girard Vertical Shaft	.50
Little Giant type	.52
Hercules type	.63
Victor and Trent types	.66
The Pelton Wheel	.475

TABLE FOR CALCULATING CAPACITY AND SPEED OF TURBINES.

A	B	C	D				
Head or Fall in Feet.	Cubic Feet of Discharge per Square Inch of Vent per Minute.	Horse-power per Square Inch of Vent at 75 per cent. Efficiency.	TO FIND REVOLUTIONS, DIVIDE THESE NUMBERS BY THE DIAMETER OF THE WHEEL.				
			Girard Type.		Little Giant Type.	Hercules Type.	Victor Type.
			Horizontal	Vertical.			
	Cub. Ft.	H.-P.					
3	5.788	.0247	1,317	1,594	1,659	2,009	2,104
4	6.684	.038	1,521	1,841	1,915	2,321	2,431
5	7.472	.0531	1,701	2,058	2,143	2,594	2,717
6	8.185	.0698	1,863	2,254	2,346	2,842	2,977
7	8.841	.088	2,012	2,435	2,533	3,069	3,215
8	9.452	.107	2,152	2,604	2,708	3,282	3,437
9	10.025	.128	2,282	2,762	2,873	3,481	3,646
10	10.565	.150	2,405	2,911	3,029	3,668	3,842
12	11.575	.197	2,635	3,189	3,318	4,018	4,209
15	12.941	.276	2,946	3,566	3,709	4,493	4,706
18	14.178	.363	3,227	3,906	4,063	4,922	5,155
20	14.942	.425	3,401	4,118	4,283	5,189	5,433
22	15.675	.490	3,568	4,319	4,493	5,442	5,699
25	16.710	.594	3,804	4,603	4,789	5,801	6,076
27	17.36	.666	3,952	4,783	4,977	6,028	6,313
30	18.3	.781	4,165	5,042	5,246	6,353	6,655
35	19.76	.984	4,500	5,447	5,666	6,864	7,188
40	21.13	1.20	4,810	5,822	6,058	7,338	7,688
45	22.42	1.43	5,102	6,176	6,425	7,783	8,152
50	23.63	1.68	5,377	6,510	6,772	8,203	8,592
60	25.88	2.21	5,891	7,131	7,420	8,985	9,411
70	27.96	2.78	6,363	7,702	8,013	9,706	10,164
80	29.88	3.4	6,803	8,234	8,566	10,375	10,864
90	31.7	4.06	7,214	8,734	9,085	11,004	11,525
100	33.41	4.75	7,604	9,205	9,575	11,900	12,151
110	35.05	5.48	7,976	......	......	......	......
120	36.6	6.24	8,330	......	......	......	......
150	40.92	8.73	9,314	......	......	......	......
200	47.25	13.44	10,757	......	......	......	......
250	52.84	18.77	12,023	......	......	......	......
300	57.88	24.68	13,172	......	......	......	......
400	66.84	38.	15,210	......	......	......	......
500	74.71	53.1	17,006	......	......	......	......

RULES.—I. To find the "Vent," or area of opening, suited to discharge a given quantity of cubic feet per minute $= \dfrac{\text{Quantity in cubic feet}}{\text{Figure in column B, opposite the head}} =$ square inches of vent.

II. To find the power resulting from above, multiply the result of I by figure in column C, opposite the head.

III. To find the diameter of the wheel selection must be resorted to. Any wheel will work at any head, but with poor results if the area of the vent is too large. The succeeding lists give facilities for selecting a size at a glance.

IV. To find the revolutions per minute, divide the figure in one of columns D by the *diameter of wheel selected.*

TABLE OF TURBINES FROM 6 INCHES TO 18 INCHES DIAMETER, UNDER FALLS UP TO 60 FEET WITH POWER AT 80 PER CENT. EFFICIENCY, QUANTITY, AND SPEED.

Heads in Feet.	6-INCH TURBINE.			8-INCH TURBINE.			10½-INCH TURBINE.			12-INCH TURBINE.			Heads in Feet.
	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	
5	.38	51	358	.57	76	255	1.15	15[illegible]	194	1.7	228	179	5
6	.5	55	392	.75	83	294	1.5	167	224	2.3	251	196	6
7	.6	60	424	.95	90	318	1.9	180	242	2.9	270	212	7
8	.75	64	454	1.1	96	342	2.3	192	262	3.4	288	227	8
9	.9	68	482	1.4	101	360	2.7	204	276	4.1	307	241	9
10	1.1	73	508	1.6	107	381	3.2	215	290	4.9	323	254	10
11	1.3	75	532	1.9	113	399	3.8	226	304	5.6	339	266	11
12	1.4	79	556	2.1	118	417	4.3	236	318	6.8	354	278	12
13	1.6	83	578	2.4	122	435	4.8	245	332	7.2	366	289	13
14	1.8	85	602	2.7	127	453	5.4	255	346	8.1	383	301	14
15	2.	88	624	3.	132	468	6.	264	360	9.	396	311	15
16	2.2	91	642	3.3	136	483	6.6	272	376	9.9	409	321	16
17	2.4	94	662	3.6	140	498	7.2	281	380	10.8	422	331	17
18	2.6	96	680	3.9	144	510	7.9	289	388	11.8	434	340	18
19	2.8	99	706	4.2	148	525	8.5	297	399	12.8	446	350	19
20	3.	101	717	4.6	152	540	9.2	304	410	13.8	457	359	20
21	3.3	104	737	5.0	156	552	10.	312	420	14.9	469	368	21
22	3.5	107	751	5.3	160	564	10.6	320	430	16.	480	376	22
23	3.7	109	771	5.9	163	579	11.8	326	440	17.1	490	385	23
24	4.1	111	786	6.1	167	591	12.2	334	450	18.2	501	393	24
25	4.3	113	801	6.4	170	603	12.9	340	460	19.3	511	401	25
26	4.6	116	818	6.9	173	615	13.8	347	469	20.6	521	409	26
27	4.9	118	835	7.4	177	627	14.9	354	478	21.7	531	417	27
28	5.1	120	849	7.7	180	636	15.2	360	487	22.8	541	424	28
29	5.3	122	863	8.	183	648	16.1	367	495	24.1	551	432	29
30	5.6	124	878	8.4	186	657	17.	373	503	25.5	560	439	30
31	5.9	126	891	8.9	189	667	17.8	379	510	26.7	569	446	31
32	6.2	128	907	9.3	192	681	18.7	385	517	28.	578	454	32
33	6.5	130	922	9.7	195	693	19.5	391	525	29.3	587	461	33
34	6.8	132	936	10.2	198	702	20.4	397	533	30.7	596	468	34
35	7.1	134	948	10.7	201	711	21.4	403	541	32.1	605	474	35
36	7.4	136	961	11.1	204	720	22.3	409	549	33.5	614	481	36
37	7.6	138	976	11.4	207	732	22.9	414	557	34.7	622	488	37
38	7.9	140	987	11.9	210	741	23.8	420	565	35 7	630	494	38
39	8.3	144	1,000	12.5	212	750	25.1	425	572	37 6	638	501	39
40	8.6	146	1,014	13.	215	762	26.	431	580	39.7	646	507	40
41	9.	148	1,027	13.5	217	771	27.	436	587	40.5	654	514	41
42	9.4	149	1,039	14.	220	780	28.1	441	594	42.2	662	520	42
43	9.7	151	1,051	14.5	223	789	29.1	447	601	43.6	670	526	43
44	10.	152	1,063	15.	226	798	30.1	452	608	45.2	678	532	44
45	10.4	154	1,077	15.6	228	807	31.2	457	614	46.8	686	538	45
46	10.7	156	1,089	16.1	231	816	32.2	462	621	48.3	693	544	46
47	11.1	157	1,102	16.6	233	825	33.2	467	628	49.9	700	550	47
48	11.5	159	1,112	17 1	236	834	34.3	472	634	51.5	707	556	48
49	11.8	164	1,121	17.7	238	842	35.4	477	640	53.1	714	561	49
50	12.2	168	1,134	18.2	241	852	36.5	482	646	54.8	721	567	50
55	14.	176	1,183	21.	252	888	42.1	505	676	63.1	758	591	55
60	16.	184	1,240	24.	264	933	48.	528	712	72.	792	622	60

The quantity of water shown in table is *when gate is fully open*; at half gate only half the water will be used.

TABLE OF TURBINES FROM 6 INCHES TO 18 INCHES DIAMETER, UNDER FALLS UP TO 60 FEET, WITH POWER AT 80 PER CENT. EFFICIENCY, QUANTITY, AND SPEED.—*Continued.*

Heads in Feet.	14-INCH TURBINE.			16-INCH TURBINE.			18-INCH TURBINE.			Heads in Feet.
	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	
5	2.6	342	145	3.2	418	128	4.6	609	120	5
6	3.4	376	168	4.2	459	147	6.	668	131	6
7	4.3	405	182	5.2	495	159	7.6	721	142	7
8	5.2	432	197	6.4	528	171	9.3	771	152	8
9	6.3	461	207	7.9	563	180	11.	818	161	9
10	7.3	484	218	8.9	591	191	13.	862	170	10
11	8.4	507	228	10.3	620	200	15.1	904	178	11
12	9.6	531	238	11.7	649	209	17.2	944	186	12
13	10.8	549	249	13.2	671	218	19.3	983	193	13
14	12.2	574	259	14.9	701	227	21.6	1,022	201	14
15	13.5	594	270	16.5	726	235	24.	1,056	208	15
16	14.8	614	276	18.2	750	242	26.4	1,090	214	16
17	16.3	633	285	19.9	778	249	28.9	1,124	220	17
18	17.7	651	291	21.4	795	255	31.5	1,156	227	18
19	19.3	669	300	23.5	817	263	34.2	1,188	233	19
20	20.8	686	308	25.4	838	270	36.9	1,219	239	20
21	22.4	704	317	27.4	860	276	39.7	1,240	245	21
22	24.	720	323	29.3	880	282	42.6	1,278	251	22
23	25.6	735	332	31.3	898	290	46.7	1,307	257	23
24	27.3	751	338	33.4	918	296	48.5	1,335	262	24
25	29.	767	345	35.3	937	302	51.6	1,363	267	25
26	30.8	782	351	37.6	955	308	54.7	1,390	272	26
27	32.6	797	358	39.8	974	314	57.9	1,416	278	27
28	34.4	812	364	42.	992	318	61.	1,442	283	28
29	36.3	827	370	44.3	1,010	324	64.4	1,468	288	29
30	38.1	840	375	46.6	1,026	329	67.9	1,493	294	30
31	40.1	854	382	48.9	1,042	334	71.1	1,518	298	31
32	42.	867	390	51.3	1,059	341	74.7	1,542	302	32
33	44.	881	396	53.8	1,076	347	78.3	1,566	307	33
34	46.1	894	402	56.2	1,092	351	81.8	1,589	312	34
35	48.1	908	407	58.8	1,109	356	85.4	1,612	316	35
36	50.2	921	412	61.3	1,125	360	89.2	1,636	321	36
37	52.3	933	418	63.9	1,140	366	91.9	1,658	325	37
38	54.4	945	423	66.5	1,155	371	95.2	1,680	329	38
39	56.5	957	429	69.	1,169	375	100.5	1,702	334	39
40	58.7	969	436	71.7	1,184	381	104.4	1,724	338	40
41	60.9	981	441	74.4	1,199	386	108.2	1,743	342	41
42	63.2	993	448	77.1	1,213	390	112.5	1,766	346	42
43	65.4	1,005	451	80.	1,228	395	116.5	1,789	350	43
44	67.8	1,017	456	82.8	1,243	399	120.5	1,808	354	44
45	70.1	1,029	461	85.2	1,257	404	124.7	1,829	359	45
46	72.5	1,040	467	88.6	1,271	408	128.8	1,849	363	46
47	75.1	1,050	471	91.3	1,283	413	132.3	1,869	367	47
48	77.1	1,061	475	94.3	1,297	417	137.3	1,889	371	48
49	79.5	1,071	480	97.1	1,309	421	141.6	1,908	374	49
50	81.9	1,081	486	100.3	1,325	426	146.	1,929	378	50
55	94.7	1,136	507	115.6	1,388	444	168.5	2,022	394	55
60	108.	1,188	534	132.	1,452	467	183.	2,142	414	60

The quantity of water shown in table is *when gate is fully open;* at half gate only half the water will be used.

TABLE OF TURBINES FROM 21 INCHES TO 44 INCHES DIAMETER, UNDER FALLS UP TO 60 FEET, WITH POWER AT 80 PER CENT. EFFICIENCY, QUANTITY, AND SPEED.

Heads in Feet.	21-INCH TURBINE			24-INCH TURBINE.			24-INCH DEEP-BUCKET TURBINE.			Heads in Feet.
	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	
5	6.1	799	97	7.8	1,027	85	9.3	1,232	85	5
6	8.	876	112	10.2	1,127	98	12.2	1,352	98	6
7	10.1	956	121	13.	1,226	106	15.6	1,471	106	7
8	12.2	1,011	131	15.7	1,299	114	18.8	1,560	114	8
9	14.6	1,074	138	18.8	1,381	120	22.4	1,657	120	9
10	17.	1,130	152	22.	1,453	127	26.5	1,743	127	10
11	19.7	1,185	155	25.4	1,524	133	30.4	1,829	133	11
12	22.5	1,239	159	28.9	1,593	139	34.6	1,912	139	12
13	25.4	1,288	166	32.6	1,654	145	39.	1,984	145	13
14	28.4	1,340	173	36.5	1,723	151	42.5	2,067	151	14
15	31.5	1,386	180	40.5	1,782	156	48.5	2,136	156	15
16	34.6	1,431	184	44.6	1,840	161	53.5	2,208	161	16
17	37.	1,475	190	48.8	1,897	166	58.5	2,276	166	17
18	41.3	1,517	194	53.2	1,951	170	63.5	2,341	170	18
19	43.3	1,559	200	57.7	2,005	175	68.	2,406	175	19
20	48.5	1,600	205	62.1	2,057	180	74.	2,469	180	20
21	52.1	1,640	210	67.1	2,109	184	80.4	2,531	184	21
22	55.9	1,678	215	71.9	2,158	188	86.2	2,590	188	22
23	59.1	1,715	220	77.	2,205	193	92.4	2,646	193	23
24	63.7	1,752	225	81.9	2,253	197	98.2	2,703	197	24
25	67.7	1,789	230	86.8	2,300	201	104.	2,760	201	25
26	71.8	1,824	234	92.3	2,345	205	110.7	2,815	205	26
27	76.	1,859	239	97.7	2,390	209	117.2	2,868	209	27
28	80.6	1,893	243	103.2	2,434	212	123.8	2,921	212	28
29	84.6	1,923	247	108.8	2,478	216	130.5	2,974	216	29
30	89.	1,959	252	114.5	2,519	219	137.4	3,023	219	30
31	94.	1,992	255	120.	2,561	223	144.	3,073	223	31
32	96.5	2,023	259	126.	2,610	227	151.	3,132	227	32
33	103.	2,050	263	132.	2,647	231	158.4	3,176	231	33
34	107.4	2,085	267	138.	2,681	234	165.6	3,220	234	34
35	112.2	2,116	271	144.	2,721	237	173.	3,270	237	35
36	117.1	2,147	274	151.	2,761	240	180.8	3,313	240	36
37	121.1	2,176	279	157.	2,798	244	188.	3,357	244	37
38	126.6	2,205	282	163.	2,835	247	195.5	3,402	247	38
39	131.9	2,233	286	169.	2,871	250	203.	3,445	250	39
40	136.4	2,252	291	176.	2,908	254	211.	3,490	254	40
41	142.4	2,290	294	183.	2,944	257	219.	3,534	257	41
42	147.4	2,317	297	189.	2,979	260	228.	3,575	260	42
43	152.9	2,347	301	196.	3,017	263	235.	3,630	263	43
44	158.3	2,373	304	204.	3,051	266	245.	3,661	266	44
45	163.6	2,400	307	210.	3,086	269	252.	3,703	269	45
46	169.1	2,427	311	217.	3,120	272	260.	3,745	272	46
47	174.6	2,452	314	223.	3,152	275	267.	3,782	275	47
48	180.3	2,479	317	231.	3,186	278	277.	3,823	278	48
49	185.8	2,503	320	238.	3,217	281	285.	3,861	281	49
50	191.8	2,532	324	246.	3,253	284	295.	3,905	284	50
55	221.	2,652	328	284.	3,410	296	340.	4,092	296	55
60	252.	2,772	356	324.	3,564	311	388.	4,277	311	60

The quantity of water shown in Table is *when gate is fully open ;* at half gate only half the water will be used.

TABLE OF TURBINES FROM 21 INCHES TO 44 INCHES DIAMETER, UNDER FALLS UP TO 60 FEET, WITH POWER AT 80 PER CENT. EFFICIENCY, QUANTITY, AND SPEED.—*Continued.*

Heads in Feet.	28-INCH "LITTLE GIANT."			33-INCH DEEP BUCKET.			44-INCH TURBINE.			Heads in Feet.
	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	Horse-power.	Cubic Feet used per Minute.	Revolutions per Minute.	
5	13.6	1,793	79	16.5	2,192	64	28.	3,735	53	5
6	17.8	1,963	87	21.6	2,405	73	37.	4,090	56	6
7	22.5	2,122	94	26.4	2,596	79	47.	4,420	60	7
8	27.5	2,268	100	33.3	2,776	85	57.	4,725	63	8
9	32.8	2,408	106	39.6	2,945	90	68.	5,010	66	9
10	38.4	2,536	112	46.8	3,103	95	80.	5,285	69	10
11	44.3	2,659	117	54.3	3,254	100	92.	5,540	72	11
12	50.5	2,776	122	61.8	3,398	104	105.	5,785	75	12
13	56.9	2,893	128	68.8	3,539	109	118.	6,025	78	13
14	63.6	3,000	133	77.7	3,679	113	132.	6,250	81	14
15	70.5	3,105	137	86.	3,789	117	147.	6,470	84	15
16	77.7	3,203	142	95.	3,924	121	162.	6,685	87	16
17	85.2	3,307	146	104.	4,046	124	177.	6,890	91	17
18	92.8	3,403	150	113.5	4,161	127	193.	7,099	94	18
19	100.5	3,496	154	122.	4,279	131	209.	7,285	97	19
20	108.7	3,588	158	132.7	4,388	135	225.	7,475	100	20
21	116.9	3,674	162	142.9	4,497	138	243.	7,655	103	21
22	125.3	3,760	166	153.3	4,601	141	260.	7,825	106	22
23	134.	3,844	170	164.4	4,705	145	279.	8,010	109	23
24	143.	3,928	174	177.	4,806	148	297.	8,185	112	24
25	152.	4,010	177	185.7	4,906	151	316.	8,355	115	25
26	161.	4,089	181	199.	5,011	154	335.	8,520	118	26
27	170.	4,166	184	213.7	5,098	157	357.	8,680	121	27
28	180.	4,233	187	219.6	5,192	159	374.	8,840	124	28
29	187.	4,317	191	231.8	5,285	162	395.	8,995	127	29
30	198.	4,392	194	249.2	5,364	164	415.	9,150	130	30
31	210.	4,464	197	255.9	5,465	167	437.	9,300	133	31
32	220.	4,536	200	268.9	5,551	170	457.	9,450	136	32
33	230.	4,608	204	281.8	5,615	173	479.	9,610	139	33
34	241.	4,677	207	294.	5,713	175	501.	9,745	142	34
35	251.	4,744	210	307.2	5,803	178	523.	9,885	145	35
36	262.	4,816	213	321.	5,887	180	545.	10,025	148	36
37	273.	4,879	216	330.7	5,969	183	569.	10,165	151	37
38	284.	4,944	218	342.6	6,048	185	593.	10,300	154	38
39	295.	5,008	221	362.	6,127	187	615.	10,435	157	39
40	307.	5,071	224	375.8	6,206	190	640.	10,565	160	40
41	319.	5,121	227	389.5	6,274	193	....	....	....	41
42	330.	5,193	229	405.	6,357	195	....	....	....	42
43	342.	5,256	232	419.4	6,440	197	....	....	....	43
44	354.	5,316	234	433.7	6,509	199	....	....	....	44
45	366.	5,376	237	452.5	6,579	202	...	....	....	45
46	378.	5,424	239	463.	6,657	204	....	....	....	46
47	390.	5,493	242	479.	6,728	206	....	....	....	47
48	403.	5,553	244	494.	6,801	208	....	....	....	48
49	416.	5,611	247	509.7	6,869	210	....	....	....	49
50	429.	5,665	249	525.6	6,942	213	....	....	....	50
55	....	....	....	....	....	....	....	....	....	55
60	....	....	....	....	....	....	....	....	....	60

The quantity of water shown in Table is *when gate is fully open;* at half gate only half the water will be used.

"TRENT" TURBINES.

Diameter in Inches.	6	7⅞	9⅞	11⅞	13⅞	15⅞	17¾	19⅝	21⅝	23⅝	27½
Cost, vertical with case	£37 $185	£40 $200	£40 $200	£48 $240	£62 $310	£75 $375	£82 $410	£90 $450	£100 $500	£110 $550	£135 $675
Cost, horizontal with case	£50 $250	£60 $300	£70 $350	£85 $425	£125 $625	£140 $700	£165 $820	£190 $950	£215 $1,075	£240 $1,200	£265 $1,325

"HERCULES" TURBINES.

Diameter in Inches.	7⅞	9	9⅞	11⅞	15	17¾	19⅝	21⅝	23⅝	27½	31½	35⅝
Cost, vertical with case	£55 $275	£58 $290	£65 $325	£75 $375	£90 $450	£105 $525	£115 $575	£125 $625	£145 $725	£165 $825	£195 $975	£235 $1,175
Cost, horizontal	£100 $500	£115 $575	£123 $615	£135 $675	£165 $825	£210 $1,050	....	....	....	....	....	....

"VICTOR" TURBINES.

Diameter in Inches.	6	8	10	12	15	17½	20	25	30	35	40	44	48	55
Cost, vertical with case	£50 $250	£54 $270	£57 $285	£60 $300	£63 $315	£70 $350	£80 $400	£105 $525	£125 $625	£165 $825	£200 $1,000	£225 $1,175	£300 $1,500	£450 $2,250

"NEW VICTOR" TURBINE. A VERTICAL PATTERN.

Diameter in Inches.	6	7⅞	9⅞	11⅞	15⅞	19⅝	23⅝	27½	31½	35⅝	39⅝	43¼	47¼	51½	55
Cost with case	£25 $125	£30 $150	£35 $175	£40 $200	£50 $250	£65 $325	£80 $400	£90 $450	£110 $550	£135 $675	£165 $825	£200 $1,000	£240 $1,200	£300 $1,500	£380 $1,900

CENTRAL DISCHARGE TURBINES, SUCH AS THE "WAVERLEY," ETC.

Diameter in Inches	6	8	10	12	$13\frac{3}{4}$	18	20	24	26	30	35	38	42	48	52	55
Cost, vertical with case.	£21 $105	£27 $135	£31 $155	£35 $175	£41 $205	£51 $255	£61 $305	£71 $355	£85 $425	£107 $535	£143 $715	£185 $925	£228 $1,140	£275 $1,375	£320 $1,600	£360 $1,800
Cost, horizontal with case.	£28 $140	£34 $170	£40 $200	£47 $235	£55 $275	£66 $330	£77 $385	£90 $450	£108 $540	£135 $675	£175 $875	£230 $1,150	£285 $1,425	£350 $1,750	£420 $2,100	£480 $2,400

"LITTLE GIANT" TYPES.

Diameter in Inches	6	$7\frac{7}{8}$	$10\frac{1}{2}$	$11\frac{7}{8}$	$13\frac{3}{4}$	$15\frac{3}{4}$	$17\frac{3}{4}$	$19\frac{5}{8}$	$21\frac{5}{8}$	$23\frac{5}{8}$	$27\frac{1}{2}$	$31\frac{1}{2}$	$35\frac{3}{8}$	$39\frac{3}{8}$	$43\frac{1}{4}$	$47\frac{1}{4}$
Cost, vertical with case.	£24 $120	£28 $140	£32 $160	£36 $180	£40 $200	£45 $225	£50 $250	£55 $275	£60 $300	£70 $350	£95 $475	£120 $600	£150 $750	£180 $900	£230 $1,150	£290 $1,450
Cost, horizontal with case.	£75 $375	£93 $465	£120 $600	£147 $735	£175 $875	£200 $1,000	£220 $1,100	£240 $1,200	£265 $1,325	£290 $1,450	....	....	....	....	....	....

"LITTLE GIANT DOUBLE" TURBINE.

Diameter in Inches.	6	8	10	12	14	16	18	21	24	24 double bucket.	28	33 deep bucket.	38	44
Cost, vertical with case..	£30 $150	£35 $175	£40 $200	£45 $225	£50 $250	£55 $275	£60 $300	£70 $350	£85 $425	£95 $475	£120 $600	£130 $650	£150 $750	£185 $925

"GIRARD."

Diameter in Inches.	$11\frac{7}{8}$ or 12	$15\frac{3}{4}$ or 16	20	$23\frac{5}{8}$ or 24	28	$31\frac{5}{8}$ or 32	36	$39\frac{1}{4}$ or 40	$47\frac{1}{4}$ or 48	55
Cost, vertical with case	£80 $400	£90 $450	£105 $525	£130 $650	£148 $740	£180 $900	£210 $1,050	£240 $1,200	....	....
Cost, horizontal with case.	£60 $300	£80 $400	....	£105 $525	....	£140 $700	....	£195 $975	£260 $1,300	£340 $1,700

Cost of Turbines.—The preceding figures of cost of various turbines are not designed to indicate any comparative advantages which each may possess, but are simply tabulated with a view to affording a comparison between the cost of a turbine installation and that of any other prime motor. The prices are in all cases copied from manufacturers' lists.

They are taken in the order mentioned in our preliminary remarks.

Water-pressure Engines.—These useful little engines are of a high comparative efficiency, and are made in several forms. The best known are those of Ramsbottom, Haag & Rigg. They usually consist of a cylinder or cylinders oscillating upon trunnions, and connected without a crosshead to a cranked shaft. An air-vessel is provided by which the shocks of the cutting-off of the supply by the movable ports, or valve-gears, are mitigated.

In the first and last mentioned types three cylinders are employed, thus dividing the duty around the circle. The writer designed one in which four were employed, each receiving pressure only during one-fourth of the stroke, and that fourth being the most effective portion upon the crank. During the remainder of the stroke each plunger drew water from its neighbor, which was at that time on its return stroke. By a simple arrangement of cross-ports each piston became its own valve. Such an arrangement may be expected to give a very high useful effect.

Other designs have been made in which, the crank being fixed, the cylinders turn around it, being enclosed in a suitable casing. This is a very useful type for capstan work. The general efficiency of these machines may run as high as 80 per cent.

The stroke of these engines is usually about 4 to 4½ times the bore of the cylinder, and the piston speed employed about 60 feet per minute.

The power is to be found as follows:

Q = Quantity of water in cubic feet per *minute.*
H = Head in feet.
The effective power will $= .00151 \times Q \times H$.

The supply of water should be free, and angles and sharp bends should be avoided. The velocity of the supply should not exceed 400 feet per minute. The proper diameter of supply pipe:

For single-cylinder engines = bore of cylinder in inches × .41 = diameter of supply-pipe in inches.
For double-cylinder engines = bore of cylinder in inches × .68 = diameter of supply-pipe in inches.

Where a high-pressure water-supply exists at a very cheap rate, these engines will be found clean and efficient motors for small powers. They may be located anywhere at will, and fixed as easily as a small steam-engine, but should not be used with pressures less than 20 lbs. per square inch.

In cases where the risk of fire would cause extra premiums for insurance, these water-engines would be found a good substitute for a steam-engine, and possess particular advantages over the latter as regards cleanliness, absence of smell, and readiness for immediate operation.

Against these must be set the liability to freeze up unless protected from the action of frost.

PARTICULARS AND COST OF THREE-CYLINDER WATER-ENGINES.

Diameter of each cylinder	2"	2½"	3"	3½"
Stroke of each cylinder	5"	5"	6"	9"
Revolutions per minute	50	50	50	50
Imperial gallons used per hour	485	815	1,565	2,775
Effective horse-power at a pressure of 100 lbs. per square inch	½	1	1½	3
Cost	£16 $90	£22 $110	£30 $150	£40 $200

Schmid's is another type of single-cylinder water-pressure engine which has given a very high percentage of useful effect under trial, and is designed for use with a high-pressure supply. It is stated that so high a percentage as 89 has been reached in effective work with these engines. In most of them by reversing the action the machine becomes a good pump, the exhaust pipe being then the suction and the supply becoming the delivery pipe.

GENERAL PARTICULARS AND POWERS OF SINGLE-CYLINDER WATER-PRESSURE ENGINES.

Diam. of Cylinder.	1½″	2″	2½″	3″	4″	5″	6″	7″	8″	9″	10″
Stroke..........	2″	2½″	3″	4″	5″	6″	7½″	9″	10″	11″	12″
Revs. per minute.	300	275	230	200	155	130	110	100	95	90	85
Imp. gals. of water used per hr.	460	930	1,525	2,275	4,200	6,900	10,260	15,000	20,920	30,080	36,780
Effective h.-p.:											
50′ head = 21.6 lbs. per sq. in.	....	...	....	45	.85	1.3	2	3	4.2	5.6	7.4
100′ head = 43.3 lbs. per sq. in.	....	...	.6	.9	1.7	2.7	4	6	8.4	11.3	14.8
150′ head = 64.9 lbs. per sq. in.	....	.57	.9		2.5	4	6	9	12.6	17	22.2
200′ head = 86.6 lbs. per sq. in.	.35	.75	1.2	1.8	3.4	5.5	8	12	16.8	22.7	29.7
250′ head = 108.2 lbs. per sq. in.	.43	.95	1.5	2.	4.2	6.9	10	15	21	28.4	34
300′ head = 129.9 lbs. per sq. in.	.5	.1	[illegible]	2.	5	8.3	12	18	25	37	44.5
Cost.....	£10 $50	£14 $70	£18 $90	£26 $130	£34 $170	£44 $220	£54 $270	£65 $325	£76 $380	£95 $475	£120 $600

SECTION IV.

CHAPTER XV.

THE POWER OF STEAM.

So great a number of duties as the steam-engine is called on to perform, naturally necessitates a very wide extent of types of construction.

We are here concerned only with those forms suited for machine-driving, and great as is the variety of detail in such engines, they may be broadly divided into two classes,

The Stationary and the Portable Engine.

These again may be conveniently subdivided into the arrangement of parts in a

Vertical or Horizontal Form.

The economical features of these engines in any of above divisions is bound up in the question of

Single or Compound Cylinders.

And finally, the chief economic point to be considered is, whether any of the above forms of engine shall be

Condensing or Non-condensing.

These eight features cover the essential differences of all steam-engines, affording sixteen variations for adoption, among which a decision can be readily reached on the question of convenience and economy, while a study of the succeeding pages will afford information on the point of comparative first costs.

The type of boiler to be employed has an important bearing on the form of engine, and may more or less decide the salient features of the type of machine to be employed.

The pressure of steam to be adopted should also be taken into account as a primary consideration.

Attendance.—The question of labour has to be carefully considered in connection with the adoption of steam-power, one disadvantage of this form of force being the necessity not merely for attendance, but for skilled attendance. A good deal has been done of late years with automatic stokers, which supplant to a great extent the labour of feeding the fires, but skilled supervision is none the less advisable, even with the aid of that ingenious apparatus.

Stokers and engine-drivers are very frequently far less skilled than they should be, and it is open to question if it be not the greater economy to pay more and obtain better services for this work.

We have already dealt somewhat fully with those questions of advisability, which go to decide for or against the use of one power or another, among which steam is so universally applicable that it comes into competition with each and all. The number of wind and water mills it has supplanted is untold, yet their use continues in certain cases to be highly economical. Perhaps the greatest recommendation of steam-power is its flexibility ; that is, the capacity of an engine and boiler may be so much varied according to requirements. Where at times some extent of extra work is needed, and other motors would refuse to give anything beyond their stated capacity, the steam-boiler may be pressed a little more and the engine responds accordingly. In cleanliness, simplicity, and required attention steam cannot be said to show favourably against water, and in economy it is now competed with by gas and oil, but it has one substantial merit, that it is generally understood, and though it has its undoubted danger when carelessly or ignorantly handled, that has been measured and discounted during its century of hard practical work for mankind.

The question of its adoption for a given duty, in compar-

ison with other powers, is so largely a matter of the cost and value of fuels, that they are consequently dealt with first in order, so as to afford an early conclusion on the general question for or against the adoption of the power of steam.

The order of consideration of this subject is therefore arranged as follows:

1. Fuels.
2. What pressure to adopt.
3. The amount of water required.
4. Condensation.

The discussion of these matters will aid a decision in favour of or against the use of steam, either on the ground of the cost of fuel, absence of water, or on local grounds of superior advantages of other powers using the same materials.

The succeeding step is, then, to define and decide upon the

Power of Steam-Engines;

and the sections following upon that subject are devoted to considering all the various types, before dealing with the proportions and forms of their boilers and chimneys.

Fuels.—Fuel is combustible matter, the value of which for practical heating purposes is dependent upon the amount of carbon it contains and its ready and complete consumption under the action of heat.

For the purpose of steam-raising numerous fuels are daily made use of, and their number tends to increase. They comprise: Wood, Bark, Coal, Lignite, coal in dust, known as breeze, or made into briquettes; Coke, Mineral Oils—animal and vegetable oils being insufficiently abundant to come into consideration; Gas—either as a natural supply from oil-beds, or derivable from coal, hydrocarbons, or as a waste product from furnaces; various waste products, such as cinder, town refuse, sawdust, megasse, and straw.

Their relative values for heating purposes are summarized in the following table, but only an average can be given, as the heating value of coal varies in different localities:

Fuels.	Relative Heat of Each.	Units of Heat Contained in Each.	Cubic Feet of Air Required to Consume 1 lb. of Fuel.	Lbs. of Water Evaporated by a lb. of Fuel Theoretically.	Average lbs. of Water Evaporated in Practice by a lb. of Fuel.	Percentage of Carbon.
COALS.						
Anthracite: Best attainable, with chimney draft.	120	14,500	......	13.30	10	....
Pennsylvania do.	124	14,221	......	14.70	....	....
" Cannel.	....	13,143	......	13.60	....	....
Indiana "	....	13,097	......	13.56	....	....
Kentucky "	....	15,198	......	16.76	....	....
" "	....	13,360	......	13.84	....	....
Best Welsh Steam Coal.........	100–110	16,200	161	......	9	89
English Wallsend	96	15,500	153	......	8	83.5
Maryland Cumberland......	....	12,226	......	12.65	....	....
Average Bituminous Coal....	86	14,000	140	13 to 14	6 to 7	....
LIGNITES.						
Kentucky Lignite	....	9,326	......	9.65	....	....
Arkansas "	....	9,215	......	9.54	....	....
Colorado "	....	13,866	......	14.35	....	....
Texas "	....	12,962	......	13.41	....	....
Average "	77	....	......	......	3 to 5½	....
COKES.						
Coke, best......	108 to	14,500	......	13.30	....	....
" ordinary..	84	13,600	142	......	6 to 8	94
Patent Fuel or Briquettes....	102	16,500	163	......	5 to 7	90
PEAT—Kiln Dried.	74 to	9,660	......	8.92	....	....
" Air Dried..	55	....	100	......	2½ to 4½	60
WOODS—All substantially alike per lb. weight..	43 to 56	7,800	80	6	3 to 4	....
CHARCOAL.......	107	14,500	......	13.30	6 to 6¾	....
STRAW..........	30	....	......	......	1.86 to 1.92	....
GAS reduced to lbs. of Coal.......	....	Say 600 units per cubic foot	....	......	4 to 6	....
PETROLEUM, Penn.	....	20,746	......	21.47	....	....
Aver. Petroleum.	....	19,500	......	......	19 to 20	....

A unit of heat is the amount necessary to heat 1 lb. of water 1 degree Fahrenheit.

Wood as Fuel.—As stated in the above table, woods have nearly the same effective value, when dry, and at per lb. weight. As, however, their relative weights vary considerably, so their relative values also vary, as indicated in the following list, giving their weight by the cord:

Wood.	Weight per Cord.	Wood.	Weight per Cord.
Hickory	4,469 lbs.	Maple	2,878 lbs.
" Red Heart..	3,705 "	Virginia Pine......	2,680 "
White Oak.........	3,821 "	Spruce............	2,325 "
Southern Pine......	3,375 "	Jersey Pine........	2,137 "
Red Oak	3,254 "	Yellow "	1,904 "
Beech	3,126 "	White "	1,868 "

For burning wood, the firebox or furnace should be larger than the proportions usual for coal, and the fire-door also should be increased in size. While, of course, wood may be burnt in an ordinary furnace proportioned for coal, it is better, even for the sake of convenience, to increase the proportions, inasmuch as *twice the bulk* of fuel has to be got into the furnace to obtain the same effect as coal.

Vertical boilers are not well adapted to this purpose, and the best boiler for general purposes with wood fuel is the locomotive type, which is usually adopted for the purpose. The extra cost entailed by such increase in a furnace of this type of boiler may be taken as follows:

Indicated Horse-power. Economic to Maximum.	2–5½	3–7	4–9	6–12	7–15	9–18	10–21	12–24
Engine Cylinder—Inches.	5	5½	6	6¾	7½	8½	8¾	9½
Extra cost of large firebox for burning wood or straws.	£3 $15	£3 15 $18.75	£4 10 $22.50	£6 $30	£7 10 $37.50	£9 $45	£10 10 $52.50	£12 $60

Indicated Horse-power. Economic to Maximum.	13½–27	15–30	18–36	21–42	24–48	30–60	38–75
Engine Cylinder—Inches.	10	10½	11½	2 of 8¾	2 of 9½	2 of 10½	2 of 11½
Extra cost of large fire-box for burning wood or straws.	£13 10 $67.50	£15 $75	£18 $90	£21 $105	£24 $120	£30 $150	£37 10 $187.50

Straws or Grasses as Fuels.—The relative value of such fuels as these naturally depends upon the difficulties and costs of transportation of more economical fuels. This may be illustrated by the fact that in some parts of Central America it is found cheaper to burn rose-wood than to import coal, while in the Western States, during a coal famine, Indian corn was largely burnt. In parts of the Asiatic East, manure is burnt as fuel, and even in Chicago some boilers are driven by stable-offal, with a small proportion of coal to keep it alight.

Dry tan-bark may be taken for the same purpose, about 2½ to 3 lbs. of which are equal to 1 lb. of coal, or when wet 6 to 8 lbs. to 1 lb. of coal. The value of cotton stalks as fuel is about 2¾ to 3 lbs. to 1 lb. of coal, while wheat or barley straw runs about 3¼ to 3¾ lbs. to 1 of coal.

Straw often forms a very economical fuel where it is plentiful and cheap, and a large use is made of it in many agricultural districts. The systems of straw-burning apparatus of Head and Schemioth and that of Elworthy are admirably effective, and their adoption should be considered in any place where straw, reeds, jungle-grass, maize, or cotton stalks, or any other dry vegetable products abound, and where wood or coal is comparatively dear or scarce. The average consumption of straw or cotton stalks is four times the weight of coal, but steam may be got up with straw quite as easily as by means of any other fuel. For this preliminary purpose, in Head's apparatus, the feed rollers, which feed the straw continuously to the furnace,

are arranged to be worked by hand when required. One man only is needed, and a boiler fitted with this straw-burning apparatus does not need more attendance than with other combustibles, as the straw is fed into the furnace by a belt from the engine when once that is started. Elworthy's is another good apparatus, possessing the special feature that it can readily be removed from the furnace-mouth and the fire then fed with other fuels. It consists of a tubular mouth-piece inserted in the fire-hole, a cast-iron frame attached to the lower part of the fire-grate, furnished with a set of rocking grate-bars, and a set of baffle-plates, deflecting the flame on to the sides of the furnace.

The cost of straw-burning apparatus is as follows:

Diameter of Cylinder of Engine.	8″	9″	10″	11″	12″	13″
	£16 $80	£17 $85	£18 $90	£19 $95	£21 $105	£23 $115

Shavings and Sawdust.—These waste materials may be burnt to good advantage, the former in the apparatuses suited for straw burning, with but slight modification. The latter, however, requires a special furnace and automatic feeding devices. It is apt to prove a somewhat troublesome material to use as a fuel, owing to its tendency to clog or "pack," and also to the large amount of gases given off under heat. It may, however, be fed in with waste wood, when it will burn well.

Spent tanbark may be utilized with it or with a small amount of coal.

Waste Fuels, such as ashes, town refuse, and refuse from coffee and sugar plantations.

The best form of boiler for burning these waste special fuels is one or other of those known as "externally fired,"

that is, those in which the furnace is a separate construction, not contained inside the boiler shell, and which may therefore be made of very wide proportions without difficulty or great expense.

Such boilers are known as the cylindrical-multitubular type, consisting simply of a shell pierced with large tubes from end to end and set in brick flues, with a large furnace below; or one of the well-known water-tube boilers made by Babcock & Wilcox, Harrison, Root, Belleville, and others.

With fuel such as town refuse the adoption of a steam-jet becomes a necessity, and for this purpose Meldrum's patent dust-fuel furnace is a practical and commercial advantage, of which many hundreds are successfully at work. It is adapted also for coke and coal dust.

Those who are ignorant of the calorific value of these waste substances, and especially of that of town refuse, would do well to inquire into the matter, and will probably be surprised to hear of the power to be derived from them. At Southampton the corporation has for many years economically employed town rubbish as fuel. In Fryer's destructor furnaces, the primary object of which is the destruction of the rubbish without nuisance, 6 cells destroy 7 tons in 24 hours, the hot gases from which pass through a multitubular boiler 10 feet long × 6 feet diameter, and provide steam for a 12″ × 24″ engine, working two 8-foot mortar mills. At Southampton, in a similar manner, sufficient steam is raised to drive a mortar mill, and a 14″ air-compressor supplying air at 60 lbs. pressure for Shone's pneumatic system of lifting the town sewage. The point to be guarded against with these rubbish fuels is the formation of clinker on the grate, or of a scale on the boiler-plates.

Sugar Cane Refuse.—Much attention has been devoted to apparatus for the proper combustion of this material, known

as "begasse," which is the refuse from the cane after leaving the crushing rolls, when it contains from 25 to 40 per cent. of wood-fibre, from 6 to 9 per cent. of sugar, and from 54 to 66 per cent. of water. In this condition it cannot be burned in ordinary furnaces, and it is customary to dry it by exposure to the air for a period of many months, or in a special kiln, which necessitates special fuel for the purpose.

Very good automatic apparatus is made, however, which will burn the begasse coming direct from the mill by utilizing the waste hot gases in heating a supply of air, which air is blown into the furnace upon the burning material. The heated air having a much increased capacity for absorbing moisture, acts rapidly in desiccating the green mass, and thus the processes of drying and burning are practically simultaneous. The combustion may be made so perfect that it is stated that the refuse or ash from the burning of 250 tons of begasse makes but about 4 barrow loads of vitreous matter.

Liquid Fuel.—Weight for weight it will be seen how largely superior mineral oil is to its competitors in heating qualities. It must not, however, from this comparison, be too readily assumed that its use is to prove an economy in equal ratio. When entirely consumed its heating capacity is, it is true, quite twice that of good coal; and even in practical operations in Russia it has been found to stand in the ratio of 1 lb. of oil to 1.77 lb. of coal. The comparison, therefore, must be made first, of the relative local prices of the two materials, where a choice lays between them. An imperial gallon of petroleum weighs about 8.2 lbs., and in the United States in purchasing it is usually taken at 6½ lbs. to the U. S. gallon, being worth at the wells about 2 cents per U. S. gallon, or in the great cities, say, 3 cents per U. S. gallon.

In Great Britain it costs from 3 pence to 4 pence per im-

perial gallon, and in both countries must compete with coal on the basis of the consumption of about 1,270 lbs. to 2,240 lbs. of coal.

It is, however, in its incidental advantages that its strong merit as a fuel is properly claimed, and especially in the reduced attention required, although it rightfully claims excellent results in actual performance.

The average result of several days' experiment, as given by Mr. Aydon, was the evaporation of 19½ lbs. of water with each pound of oil.

The following advantages are claimed for its use :

I.—Reduction of weight of fuel of 40 per cent.

II.—Reduction of bulk of fuel by 30 per cent. (See note following.)

III.—Reduction of stokers in the proportion of 4 to 1.

IV.—Prompt kindling of fire.

V.—Prompt extinguishing of fire.

VI.—Cleanliness and freedom from ash.

VII.—No loss of heat by reason of opening the fire doors to attend to the fire.

VIII.—Rapidity of raising steam.

IX.—Freedom from smoke.

Against these must be put as disadvantages :

The high cost of oil in certain localities, such as countries where a monopoly exists, as in Spain, etc.

The smell of burning oil.

Care required not to burn out parts of the furnace or plates with the intense local heat at the point of combustion.

Liability of low grade oils to clog in the pipes and in the injecting apparatus.

Naturally, these mechanical difficulties may be overcome by proper arrangements.

The Stowage of Fuels, or space occupied by them, being relatively as follows :

1 ton of coal requires 45 cubic feet of space.

1 ton of petroleum requires practically the same space, but its value for heating purposes per lb. weight being greater, less need be carried for a given power.

1 ton crude petroleum	=	275 impl. gallons		approximately, according to degree of refinement.
45 cub. feet "	=	280.35 "	"	
1 cub. foot "	=	6.23 "	"	
1 impl. gallon "	=	8.2 lbs.		

Oil-Burning Furnaces.—For the application of the system of burning liquid fuel no extensive alteration need be made in the ordinary coal furnace.

The fire-bars should be covered with thin slabs of fuel, on top of which should be placed a thick layer of cinders, and the ashpit doors may be entirely closed. The oil is then led into the furnace by a small pipe, from the end of which the oil is arranged to drop. This end may be reduced to about 1/8 inch diameter, and the oil will fall at the rate of about 3 gallons an hour, a sufficient supply for a 25-horse-power boiler. The dropping oil is met by a jet of steam and driven into fine spray upon the heated cinders.

Portable engines are now made on a similar system, provided with a special injector for steam and oil, the latter drawn from a small galvanized tank, in which is a copper warming coil.

Gas Fuel.—The burning of town-supply coal-gas under boilers is manifestly not an economical operation. Not only has the original coal from which it is made to be paid for, but the gas company's profit has to be included.

Illuminating gas is, in effect, too good for the purpose. A commoner form of gas would give equal results.

This is plainly shown in the economical use of what is known as producer-gas in furnaces, where the fuel and the steam from a jet are decomposed together, forming a large body of hydrocarbon gas. One form of such apparatus is

known as the "Water-Gas" furnace, but probably the most practical type of apparatus for the production of this cheap form of gas is that known as the "Dowson."

Dowson Gas.—The gas produced by its means is a mixture of the following components, as ascertained in an official test by Dr. C. Monaco, 1890.

Components.	Per Cent.	Weight per 1.000 Cubic Feet.
Carbonic Acid	.084	10 lbs.
Oxygen	.009	.78 lb.
Hydrogen	.164	.89 "
Carbonic Oxide	.275	20.94 lbs.
Nitrogen	.467	35.59 "

Comparing this gas with good illuminating gas the latter stands at considerable calorific advantage, being as 5,000 to 1,216 on the part of the Dowson gas, or say as 4 to 1 in heating value.

But the cost of producing the Dowson gas is so much less than that of illuminating gas, being only about 4 pence per 1,000 cubic feet, that for an equal heating result the advantage is in its favour, or

4,000 cubic feet @ 4*d.* per thousand = 1*s.* 4*d.*, against 1,000 cubic feet of ordinary gas, which varies in value from 1*s.* 8*d.* in North English towns to 4*s.*, 5*s.*, and even 6*s.* in some places.

It is thus evident that for the economical use of gas as a fuel, special apparatus is needed, and it will remain the fact that when such gas is produced, its most effective use will be by its explosion in a gas engine.

For very small powers, such as for domestic use, gas may be found so convenient that its cost may be willingly incurred.

(See vol. cxii. Transactions Inst. Civ. Engrs., 1892–3, pt. ii., "Dowson on Gas Power," also vols. lxxiii. and lxxxix.)

Waste Hot Gases as Fuel.—These stand on a totally different basis of economy, and where they exist as a waste product from furnaces with any regularity, should certainly be made use of, provided circumstances admit of the construction of flues to carry them to a boiler.

The proportions of such flues are governed by their length, and rules upon this subject will be found in Chapter XXX., on Chimneys.

CHAPTER XVI.

PRESSURES OF STEAM.

For Single Cylinders.—The most usual commercial pressures of steam are 60 to 80 lbs. per square inch, which, for all single-cylinder engines, give very excellent results. The quoted prices in most catalogues of engines are established on proportions proper to these pressures, and it will not be safe to take any ordinary engine to be used with pressures exceeding 80 lbs. Nor would it be an economy to use a higher pressure in a single cylinder, for reasons afterwards stated.

For Double or Compound Cylinders.—If a compound engine is decided upon, the pressure should be raised to at least 100 lbs. per square inch, the best results being attainable at about 120 lbs. per square inch.

For Triple Compound Cylinders.—If the pressure is to exceed 125 lbs. per square inch, a triple compound, or "triple-expansion," engine should be employed, with which the best results are obtained both in economy and also as regards ease of turning the shaft. The pressure most widely adopted for this purpose is 160 lbs. per square inch.

For Quadruple Compound Cylinders.—For pressures exceeding 170 lbs. per square inch, a quadruple compound engine should be adopted, by which effective use may be made of the steam up to a pressure of 250 lbs. per square inch.

It will therefore be seen that the decision as to the pressure to be used will usually follow on the point of economy, and that is largely involved in the question of whether or no the engine is to be *compound.*

High pressures are the present tendency, and with justice, as the use of same in high-class engines invariably results in economy.

TABLE OF THE TEMPERATURES OF STEAM AT DIFFERENT PRESSURES.

Pressure in Lbs. per Square Inch above the Atmosphere.	Degrees of Heat, Fahrenheit.	Pressures Suitable for
60.3	307.5	Ordinary single cylinders.
65.3	312.0	
70.3	316.1	
75.3	320.2	
80.3	324.1	High-class single cylinders.
105.3	341.1	Double compound cylinders.
125.3	352.9	
155.3	368.2	Triple compound cylinders.
165.3	372.9	
175.3	377.5	

$$\text{Degrees Centigrade} = \frac{5 \times (\text{Fahr.} - 32)}{9};$$

$$\text{Degrees Reaumur} = \frac{4 \times (\text{Fahr.} - 32)}{9}.$$

CHAPTER XVII.

COMPOUND OR NON-COMPOUND ENGINES.

COMPOUND engines are more economical than single-cylinder engines, even when the latter are made condensing, mainly because of the higher pressures at which they can be worked without involving excessive strains, and by the more extended use they make of a given quantity of steam.

Of course the same amount of use of a quantity of steam may be made in one cylinder of proper proportions, but the fall in temperature during the entire process is so great that the cylinder-walls cause serious condensation on the admission of the new steam. The practical economy of the use of the steam in two cylinders is considerable, and the additional advantage is gained of having two cranks on the turning shaft, by which more even working may be secured.

The second cylinder may, of course, be part of a separate engine altogether, provided its capacity and speed are exactly proportioned to receive, and use, the steam issuing from the high-pressure cylinder.

Two low-pressure cylinders may also be used, thus making a tri-cylinder engine, with which very easy turning may be performed. But this would cost nearly as much as a regular triple-expansion engine, which would afford better economy. The work for which a compound engine is inadvisable is that in which the major portion of its work is very variable and lays below its normal or regular power. Where this is the case, a single-cylinder condensing engine will frequently give better results. Where, however, the work is reasonably regular, and unless first cost stands in the

way, a compound engine should be adopted for all general purposes, and references further on will show that by the efforts of various manufacturers there are now on the market excellent compound engines from the smallest sizes upward, at commercial prices.

Chimneys for Compound Engines.—A chimney for the boiler of a compound engine does not obtain much assistance in draft from the blast of the exhaust, and may therefore need to be increased in height. Where, however, brick chimneys are built according to rules given in Chapter XXX., the steam jet or blast would make no economical difference to them, and the steam may as well in every case be utilized down to the lowest limit of pressure found to be practical, or be entirely condensed.

Amount of Water Required for a Steam-Engine.—As previously pointed out, water is a prime necessity to all steam-engines, and however economical a use is made of it, some waste is bound to occur. In many instances the cost of water is an important factor.

1. Water may be very dirty, and require the expense and employment of filtration machinery.
2. Its supply may fall to a minimum in summer months and require storage or great economy in use.
3. It may be derived from an expensive town supply.
4. It may need pumping machinery to lift it to a sufficient height for use.

Such matters need consideration when a type of engine is to be selected.

The average water consumption in steam-engines may be taken roughly as follows:

Non-condensing engines........	about 40 lbs. per I.H.P. each hour of work.
Where these engines are supplied with a condenser	about 30 lbs. per I.H.P. each hour of work.
Compound engines with a condenser.......................	about 20 to 22 lbs. per I.H.P. each hr. of work.

Triple compound engines	about 15 to 18 lbs. per I.H.P. each hr. of work.

These results vary very considerably with various types of engines.

Thus the most excellent effects attainable on trials are very much better, and such records as the following have been made with very moderately sized engines:

A 20-H. P. non-condensing single-cylinder engine by Paxman.....	22 lbs. per I.H.P. per hour of work.
A 20-H. P. non-condensing single-cylinder engine by McLaren....	23.9 lbs. per I.H.P. per hour of work.
A 20-H. P. double compound non-condensing engine by Paxman..	17.8 lbs. per I.H.P. per hour of work.
A 20-H. P. double compound non-condensing engine by McLaren.	19.8 lbs. per I.H.P. per hour of work.

While large triple-compound condensing engines have used as little as 14 lbs. per I.H.P. per hour of work.

These high results are, however, only to be relied on with first-class machinery specially designed for the duty undertaken. It will be safer for the prospective user to reckon on the larger figures. A ready rule for good new engines is to divide the figure 200 by the square root of the boiler pressure:

$$\frac{200}{\sqrt{\text{pressure}}} = \text{lbs. of water per I. H. P. per hour.}$$

All, or nearly all, the above consumption may be, however, *usefully* re-converted into feed-water and used over again by means of condensation, with which we now proceed to deal.

Water for Condensation.—The amount of water required for condensation is a totally different affair, and is more or less dependent on circumstances dealt with in the following chapter.

Impurities in Water.—This is a matter of much importance, as nearly all waters contain some foreign substances which tend to produce scale or sediment in the boiler, and a great amount of future annoyance and expense may be saved sometimes by ascertaining beforehand the character of the water proposed to be employed for steam-raising. Carbonates and sulphates of lime and carbonate of magnesia are the most usual components of troublesome scaling, and one-sixteenth of an inch of such scale may mean the loss of as much as 13 per cent. of fuel, while one-fourth of an inch will cause a loss of 38 per cent. For very muddy water, especially if it hold lime in solution, filtration must be provided.

Some forms of feed-heaters will precipitate such substances, before they reach the boiler, to a great degree.

Lime salts are more soluble in cold than in hot water, and most of them are deposited before the water reaches 320° Fahr. In fact, nearly all the substances held in solution by water are parted with when that water is evaporated into steam, or when frozen into ice.

CHAPTER XVIII.

CONDENSATION.

THE wastefulness of turning exhaust steam loose into the atmosphere, to dissipate therein a part of the heat which it has cost money to impart to it, is apparent to the most uninformed observer. Its value as a means of increasing draught in chimneys cannot be set against this loss as a serious offset, though in special cases, such as the locomotive, it becomes so from force of circumstances.

But when it is found that by extracting the heat from it, it may not only be made use of again as feed-water, and thus avoid a corresponding amount of re-heating, but, in addition, that its effect on the action of the engine itself may be made a substantial addition to its power, the last possible particle of sense is cut out of the original wastefulness.

Condensation may be made use of in several ways, and these may be judiciously combined into a great working economy by the removal of pressure from the back of the piston, and by the use of part or all of the cooled steam as already heated feed-water for the boiler.

The amount of heat left in exhaust steam is ascertainable if its pressure be known, corresponding to the following:

TEMPERATURES OF EXHAUST STEAM.

Pressures Above the Atmosphere.	Degrees Fahrenheit.
Atmospheric pressure	212 degrees.
5.3 lbs. per square inch......................	228 "
10.3 " " " "	240.1 "
15.3 " " " "	250.4 "
20.3 " " " "	259.3 "

The extraction of the whole of this heat would mean an absolutely complete condensation. In practice, a good result is sufficient condensation to remove 12 lbs. of average pressure from the near side of a piston, which, measured in the customary method, is approximately equal to 26 inches of mercury.

Vacuum.—This removal of pressure does not in itself give power, but permits of an equivalent amount of extra effectiveness in the power on the other side of a piston.

A fair idea of the percentage of gain derivable from a good vacuum applied to a previously non-condensing engine may be obtained from the following:

$$\frac{\text{Area of piston in sq. in.} \times \text{piston speed in ft. per min.} \times 12 \text{ lbs.}}{33{,}000}$$

= the horse-power represented by the vacuum referred to.

The following table will afford the information in a form easy of reference and sufficiently approximate for general purposes:

TABLE OF ECONOMY RESULTING FROM A VACUUM OF 12 LBS. PER SQUARE INCH AT DIFFERENT PRESSURES AND POINTS OF CUT-OFF.

Initial Steam Pressure.	Points of Cut-off.							
	1/6	1/4	1/3	3/8	1/2	5/8	2/3	3/4
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
150	21	14.7	12.25	11.4	9.65	....	....	....
140	23	15.8	12.7	12.1	10.5	....	....	....
125	26	17.7	14.5	13.2	11.7	....	....	....
120	27	18.5	15.1	14	12.1	11.1	....	....
110	29	20.5	16.5	15.4	13	12	....	....
105	30	21.5	17.1	16	13.7	12.4	....	....
100	32	23	18.2	16.8	14.5	12.8	....	....
90	35	26	20.5	18.7	16	14.6	....	....
80	39	28	23.4	21.8	18.3	16.3	16	....
75	42	29.2	25	23.1	19.1	17.3	16.9	....
70	..	32	27	25	21.5	18.9	18	17.5
65	..	34.8	29.1	27	23	20.1	19.5	18.5
60	..	37.5	30	28.5	25	22.5	21.8	21
50	..	....	37.5	34.5	29	27.2	26.6	26

There are a number of methods of condensation, partial, or complete, and from the facts that follow with reference to these it will be seen that the adoption of some form of condensation is a matter of no very serious outlay, and that it requires considerations of a peculiarly favorable character as regards fuel to outweigh the advantages.

Partial Condensation.—The crudest form is that of turning the exhaust steam into a tank of water. This is not even the best way of heating the water, and, although some improved nozzles have been made to overcome the difficulties, it is apt to produce noise and some amount of back pressure on the piston, sometimes more than compensating the advantage gained.

A Partial Condenser.—A very simple partial condenser of exhaust steam for small engines may be made in an easy manner. Erect a large pipe, either of sheet-iron, or even of drain-pipes, and turn the exhaust-pipe upwards into the centre of it. Rapid condensation of the rising steam column will take place from radiation to the air surrounding the pipe, and the condensed steam will fall in a rain to the bottom of the pipe, where there should be a drain to the hot-well, or a tank communicating with the feed-pump.

The efficiency may be still further increased by a supply of cold water through a perforated pipe situated at a convenient distance up the pipe. This simple apparatus might be employed in 90 cases out of 100 where the exhaust steam is now thrown wastefully into the atmosphere, and would give a considerable economy over the use of cold feed-water.

Feed-heaters.—The economy due to absolute condensation of the whole of the steam of an engine may not be practicable, but there is not, in almost every case, any reason why the partial economy, often a very appreciable amount, of the system known as feed-water heating, should

not be adopted. The cost is really trifling and the resultant economy is serious.

The temperature of the exhaust steam (see table of temperatures following) is considerable, even with the most economical use of it in the cylinder and consequent low pressure of the exhaust, and in very many small engines it is exhausted at a pressure of about 5 to 20 lbs. per square inch.

Pounds of Pressure per Square Inch.		Temperature, Fahrenheit.
Atmosphere Included.	Above the Atmosphere.	
1 atmosphere.	Atmospheric pressure =	212 deg. = boiling point of water.
At 20 lbs.	say 5.3 lbs.	228 degrees.
At 25 "	" 10.3 "	240.1 degrees.
At 30 "	" 15.3 "	250.4 "
At 35 "	" 20.3 "	259.3 "

The more of this heat that can be conveyed to the feed-water the less the fire will have to add to it.

A very simple apparatus will do a good deal toward these results. A large tube closed at each end may be made to contain the feed-water, through which the exhaust steam is led by a copper coil pipe in the interior, or through a series of straight brass or iron pipes passing from end to end of the receptacle.

A large number of forms of feed-heaters are manufactured, many possessing special merits in accessibility, compactness, and efficiency. For the purposes of comparison it would be necessary to devote a large amount of space to them, but this is not required for a decision for or against their use.

Sufficient may be gained from the following list of costs to indicate the moderate outlay required to secure the advantages of feed-heating:

HORIZONTAL FEED-WATER HEATERS.

Length	3' 11"	4' 6"	5'	5' 6"	6'	6' 6"	6' 9"	7'
Cost.........	£6 $30	£7 10 $37.50	£8 $40	£10 $50	£14 $70	£17 $85	£21 $105	£24 $120
Suited for an engine of effective h.-p.	9	12	14	17	26	30	35	45

The percentage of saving at any pressure, resulting from the heating of the feed, may be ascertained in the following manner :

Let B = temperature of the steam at boiler pressure (see tables of temperatures preceding).

t = the temperature of the feed-water *before* heating.

h = the temperature of the feed-water *after* heating.

$$\text{Then the percentage of saving} = \frac{100 \times (h - t)}{B - t}.$$

See also Table of Saving, on next page.

The admission of cold feed-water to steam boilers, especially in the case of those working under the higher pressures, causes an unequal expansion and contraction of the plates, and is a fruitful cause of leakage, so that the heating of the feed-water is directly beneficial to the life of the boiler supplied.

Fuel Economizers.—Where the exhaust steam is *not* available for feed-heating by reason of its use for other purposes or its condensation to a low temperature, it still remains advisable to provide for the heating of the feed-water, and for this purpose, under those circumstances, no better apparatus exists than the so-called Green's economizer, which is an arrangement of pipes placed in the boiler flues, intercepting the hot gases as they pass to the chim-

ney. These pipes are placed vertically, usually in the main flue, and are slightly under 4 inches diameter inside and $\frac{5}{16}$ inch thick, thus measuring $4\frac{9}{16}$ inches outside diameter

TABLE OF THE SAVING PER CENT. IN FUEL EFFECTED BY HEATING FEED-WATER AT 60 LBS. PRESSURE PER SQUARE INCH.

Temperature of the Feed, without a Feed-heater.	Final Temperature of the Feed-Water after Passing Feed-Heater.						
	120°	140°	160°	180°	200°	250°	300°
Fahr.°	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
32	7.5	9.2	10.9	12.36	14.30	19	22.9
35	7.25	8.96	10.66	12.09	14	18.34	22.6
40	6.85	8.57	10.28	12	13.71	17.99	22.27
45	6.45	8.17	9.9	11.61	13.34	17.64	21.94
50	6.05	7.71	9.5	11.23	13	17.28	21.61
55	5.64	7.37	9	10.85	12.60	16.93	21.27
60	5.23	6.97	8.72	10.46	12.2	16.58	20.92
65	4.82	6.56	8.32	10	11.82	16.20	20.58
70	4.40	6.15	7.91	9.68	11.43	15.83	20.23
75	3.98	5.74	7.5	9.28	11	15.46	19.88
80	3.55	5.32	7	8.87	10.65	15	19.52
85	3.12	4.9	6.63	8.46	10.25	14.7	19.17
90	2.68	4.47	6.26	8	9.85	14.32	18.81
95	2.24	4.04	5.84	7.65	9.44	13.94	18.44
100	1.80	3.61	5.42	7.23	9	13.55	18
110	.90	2.73	4.55	6.38	8.2	12.76	17.28
120	....	1.84	3.67	5.52	7.36	11.95	16.49
130	....	.92	2.77	4.64	6.99	11.14	15.24
140	....	....	1.87	3.75	5.62	10.31	14.99
150	....	....	.94	2.83	4.72	9.46	14.18
160	....	....	....	1.91	3.82	8.59	13.37
170	....	....	....	.96	2.89	7.71	12.54
180	....	....	....	....	1.96	6.81	11.70
200	....	....	....	....	....	4.85	9.93

by about 9 feet in length, connecting a series of top and bottom cast-iron boxes made of a special mixture of Scotch pig-iron and hematite, and tested to a pressure of 650 to 1,000 lbs. They are suited to a safe load of 200 lbs. per square inch. Through these pipes the feed-water is pumped to the boiler, absorbing a good deal of waste heat otherwise

passing up the chimney, represented by the reduction of their temperature from about 650° Fahr. to 350°, while the temperature of the feed-water is increased about 150°, or, when introduced, say, at 62°, it is brought up to 212°. It is not advisable to cool the gases to a greater extent than 350°, but where they are hotter than 650°, or in great volume, the water may be raised to 300° and even 316° in these economizers.

The quantity of water held by each pipe of the economizer is about $5\frac{1}{8}$ gallons, or, including top and bottom boxes, 6 gallons. Therefore, to find the contents of an economizer multiply the number of pipes by 6.

About 8 pipes go to a ton weight, and the widths of chamber required to contain the apparatus are as follows:

Apparatus of	4	pipes	wide	= 3	feet	4	inches	inside chamber.
"	5	"	"	= 4	"	0	"	"
"	6	"	"	= 4	"	8	"	"
"	8	"	"	= 6	"	0	"	"
"	10	"	"	= 7	"	4	"	"

Where side dampers are fitted to afford room for a man to pass alongside add 9 inches extra width to each of above.

The vertical pipes are kept free from the deposit of soot by scrapers fitted round them and raised and lowered slowly by an automatic apparatus operated by a belt from the nearest shafting. To this is largely due the high efficiency attained by this apparatus.

One further important advantage of feed-heating is that where the feed-water is sedimentary, and especially where much lime is present, a large part of the solids contained in the water is precipitated in the feed-heater, and if proper arrangements are provided for cleaning out the apparatus at intervals the feed-heater thus answers the additional purpose of a very efficient water-purifier.

Air Condensers.—This is a modification of what is known as the surface-condensing system, and is employed with much success in many north-country mills where water is valuable. The condensing area is increased by adding pipes to a proportionate extent, and the whole arrangement is fixed in some exposed position, frequently on the roof, where the air can freely circulate round every tube.

This system makes economical use of the factor which causes so much loss in the working of engines, viz.: condensation by means of radiation. This may be well understood from the following comparison :

In a steam pipe 12 inches diameter × 50 feet long, carrying steam at 100 lbs. pressure per square inch, the losses are :

In an uncovered pipe exposed to air = 131 lbs. of water per hour.

In a pipe covered with 1½ inches of clothing material = 15 lbs. of water per hour.

Material for Condenser Surfaces.—The conducting power of iron being 233 thermal units, compared with 555 units on the part of copper, the use of the latter is better for the purpose of conveying the heat to the air (or water), or, if expense prevents its employment, then brass gives better results, and both give freedom from oxidation and corrosion.

Jet Condensing.—This is a form of condensation very widely adopted, and is applied either direct to the engine or by a separate apparatus, with pump to convey the resulting body of water away.

It requires, however, a large body of water, about 20 times the amount of the water used by the engine in the form of steam.

The approximate quantity is found in the following manner:

$$\left.\begin{array}{l}\text{Cubic feet of condensing}\\ \quad\text{water required per in-}\\ \quad\text{dicated H.-P. per } \textit{min.}\end{array}\right\} = \left\{\frac{\text{The temperature of the steam in deg. of F.} \times .00304}{3}\right.$$

TABLE OF TEMPERATURES OF STEAM.

Pressure.	Degrees Fahrenheit.	
At atmospheric pressure..............	212	
" 5.3 lbs. per square inch above....	228	
" 10.3 " " "	240.1	Exhaust pressures.
" 15.3 " " "	250.4	
" 20.3 " " "	259.3	
" 30.3 " " "	274.4	
" 35.3 " " "	281	
" 40.3 " " "	287.1	
" 45.3 " " "	292.7	
" 50.3 " " "	299	
" 60.3 " " "	307.5	
" 65.3 " " "	312	
" 70.3 " " "	316.1	Pressures of ordinary single-cylinder engines.
" 75.3 " " "	320.2	
" 80.3 " " "	324.1	
" 105.3 " " "	341.1	Pressures suited to double compound engines.
" 125.3 " " "	352.9	
" 155.3 " " "	368.2	
" 165.3 " " "	372.9	Pressures suited to triple compound engines.
" 175.3 " " "	377.5	

It will thus be seen that there should be a good supply to be relied upon in order to make use of the system of jet condensation.

Where a stream cannot be relied upon the result may be attained by establishing a pond, tank, or reservoir of sufficient capacity to ensure that the entire body of water shall not become heated unduly.

A rough rule, very generally adopted in practice, is to allow a storage capacity in the reservoir equal to the total amount of injection water which would be passed through

the engine in the course of a day. This rule, however, is manifestly capable of a considerable amount of modification, and the reservoir capacity is capable of variation within pretty wide limits, according as the water is, or is not, being renewed with a running stream. With a good supply of fresh cold water running into the reservoir the temperature can be kept low even with a small capacity, while, in the case of total absence of a running stream and with poor facilities for cooling, as in the case of reservoirs underneath buildings, a capacity equal to a day's supply may be inadequate. It may be taken, however, that in order to secure a good vacuum the temperature of the injection water should not from any reason be allowed to rise much over 100° F.

Air-pump Condensers.—The most usual method of jet condensation is to attach a pump, known as the "air-pump," to some part of the mechanism and connect it to the exhaust passage of the engine by suitable pipes with non-return valves. The cold water is injected into this pump (or may be sucked up by it), and, meeting the exhaust steam, instantly condenses it, when the united volume of water is swept out of the pump by the return stroke of its plunger. With a proper proportion of plunger and of injection water, the result may be a very thorough condensation, almost to the point of destroying all pressure against the engine piston, nearing the point of a complete vacuum.

The extent of this non-pressure is measured in inches of mercury depressed by the atmospheric pressure against the absence of pressure on the inner side of the fluid.

An ordinary practice is to attach the "air-pump" to the back end of a horizontal engine. If a compound, it should be attached to the rear of the low-pressure cylinder whence the exhaust emanates, so as to keep the passages as direct as possible.

Such condenser pumps are, in single-cylinder engines, usually about $\frac{1}{11}$th of the diameter of the cylinder, their

stroke being the same. One-half this capacity is sufficient for compound engines, while in compound surface-condensing engines it may be as low as $\frac{1}{10}$th of the low-pressure cylinder capacity. Calculating by cubic capacity, take ¼ of the cylinder capacity, not less.

The cost of such condensers for horizontal engines runs about as follows:

Indicated Horse-Power about	24	36	42	48	60	75	90
Cost of Condenser........	£40 $200	£50 $250	£55 $275	£60 $300	£65 $325	£80 $400	£90 $450

Indicated Horse-Power about	105	160	195	240	350	480
Cost of Condenser........	£125 $625	£140 $700	£150 $750	£170 $850	£195 $975	£250 $1,250

Separate air-pumps on the duplex system are also made and are very efficient. They will maintain a steady degree of vacuum and are free from complication, running for long periods without attention. Their proportions are similar to those dealt with in the succeeding remarks.

Independent Pump Condensers.—A very admirably effective apparatus is made by the Worthington Pumping Engine Company and by others, consisting of an independent duplex pump fitted with an injector-condenser so arranged that the momentum of the jet of water and exhaust steam assists the pump in maintaining the vacuum. The duplex system of pump is well suited to this duty, as its action is practically continuous and free from pause in the flow of water, while its speed can be exactly proportioned to any duty demanded by the engine. The valves are so arranged that in case of any surplus of water, flooding or stoppage

of the pump, the exhaust steam may escape through them and thus no flooding of the engine can occur.

The whole apparatus is self-contained and only requires pipes to make the necessary connections.

The following list gives the proportions of these pump-condensers. Their own steam may be included in their condensation, or may be made use of for feed-heating:

	Diameter of						
Engine Exhaust.	Injection Pipe.	Discharge Pipe.	Steam Pipe to Pump.	Pump Exhaust.	2 Steam Cylinders.	2 Water Cylinders.	Stroke of Pumps.
Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
4	2½	2	¾	1¼	5¼	4¾	5
5	3	3	1	1½	6	5¾	6
6	4	4	1½	2	7½	7½	6
6	4	4	1½	2	7½	7	10
7	4	4	1½	2	7½	7	10
8	5	5	1½	2	7½	8½	10
8	5	5	1½	2	7½	8½	10
9	6	6	1½	2	7½	10¼	10
10	7	8	1½	2	9	12	10
12	8	10	2½	3	12	14	10
12	8	10	2½	3	12	15	10
14	10	10	2½	3	12	15	15

The ability of these pumps to elevate the heated discharge renders the apparatus of special value in certain cases, while the pump may be readily arranged to act as a fire-pump in emergencies. For sugar factories they are especially suitable.

Falling-column Condensers.—A simple adaptation of the forces due to gravity may be made to produce most excellent results at much less cost than the foregoing, in the shape of a condenser known as the *falling-column condenser*, in forms invented by Korting, Ledward, Bulkley, and Ransom.

In these the primary necessity is plenty of water, at least

25 times the feed, but should a natural fall of water of about 30 feet be available for use a high economy may be reached with any of the above-mentioned apparatuses.

In the two latter a closed cold-water tank is situated at the top of a pipe of 33 feet height. To the tank the exhaust is led from the engine. The water pours freely into the upper part of the tank on to a perforated plate about half way down its depth. The exhaust is introduced below this plate and entire condensation takes place. The resultant body of water condensing and condensed water drops down the pipe, and the natural suction due to 33 feet fall is thus almost entirely made use of.

In Korting's and Ledward's apparatuses the tank is dispensed with, and the height of the pipe may be reduced to 15 feet. The exhaust steam passes through an ejector pointing down the vertical pipe, and, issuing from the ejector, it draws with it cold water from a chamber surrounding the ejector. Condensation ensues just as the resultant body of water enters the down-fall pipe.

With an ample water-supply I have seen one of these ejector-condensers registering steadily a vacuum of 29.4 inches of mercury for hours together, the work of the engine varying greatly all the time, as it was employed on saw-mill work.

Surface Condensers.—This is the best form of condenser for reliable and complete results. It is the method universally adopted at sea, and in very many cases on land.

The exhaust steam is passed through a large number of thin metal tubes, over which water is caused to flow.

For industrial purposes it is not always necessary to have a complete self-contained apparatus. Excellent surface-condensers for many large mills are arranged in any convenient spot, to which the exhaust is led by a pipe.

Over the condenser pipes a supply of water is allowed to flow, and this can be exactly proportioned to the require-

ments or economy of the case. Thus the water may be reduced in volume and thereby increased in total temperature, or the hottest portion of the condenser pipes may be set apart with this view, whereby enough water may be heated to nearly boiling-point to make up the amount required to feed the boiler in addition to the condensed steam.

The rule in marine engines is to proportion the condensing surface to the heating surface of the boilers, thus,

$$\text{Heating surface} \times 0.7 = \text{condensing surface.}$$

For land purposes one-half the boiler heating surface may be considered sufficient. For further information, see Chapter XXIV.

Gain in Condensation.—A good idea of the relative advantage to be gained from adopting condensation with a single-cylinder engine is afforded by the following comparative table of engines of very widely used sizes :

COMPARATIVE TABLE OF SINGLE-CYLINDER ENGINES WITH AND WITHOUT CONDENSATION.

Cylinder.		Revolutions per Minute.	Indicated Horse-Power of							
			Most Economical Load				Maximum Load			
Diam.	Stroke.		With a Boiler Pressure of 60 Lbs.		With a Boiler Pressure of 80 Lbs.		With a Boiler Pressure of 60 Lbs.		With a Boiler Pressure of 80 Lbs.	
Ins.	Ins.		Non-Cond'g.	Con-densing	Non-Cond'g.	Con-densing	Non-Cond'g.	Con-densing	Non-Cond'g.	Con-densing
11	22	96	30	40	36	45	42	50	48	55
12	24	88	35	45	42	52	49	60	56	65
13	27	78	40	54	48	60	56	70	64	75
14½	30	70	50	67	60	75	70	85	80	95
16	33	65	62	80	75	95	87	105	100	120
17½	36	60	75	100	90	115	105	130	120	145
19	36	60	87	115	105	140	122	150	140	170
20	42	65	..	...	160	200	...	...	210	240
22	42	65	..	...	195	240	...	...	255	290

Heating Factories by Exhaust Steam.—Much economy results from the use of exhaust steam to warm factories, heat drying rooms and closets, and dry cement floors, etc.

Data for arriving at the amount thus to be made use of are as follows:

To raise the temperature of a room from freezing-point to 60°, and there maintain it (say 30° rise), allow 1 superficial foot of steam-pipe for each 6 superficial feet of glass in the windows; or, allow 1 superficial foot of steam-pipe to every 120 square feet of wall and ceiling.

SURFACE OF TUBES IN SQUARE FEET PER ONE-FOOT LENGTH.

Diam. in Ins.		¼	½	¾
1	.261	.327	.392	.458
2	.523	.589	.654	.720
3	.785	.850	.916	.981
4	1.04	1.112	1.178	1.243
5	1.30	1.374	1.439	1.505

P = temperature of the exhaust steam;
T = temperature required in building;
t = temperature of external air;
C = cubic feet of air to be warmed per minute.

Then the length of pipe necessary is

$$\frac{(P-t)\times(T-t)}{P-T}\times .009 \text{ for 2 in. pipe,}$$

or .006 for 3 in. pipe,
or .0045 for 4 in. pipe.

Water Required for Surface Condensing.—The amount of water required for surface condensing of course varies with the amount used by the engine. If the engine is wasteful, or with work much below its normal duty, it may stand as high as 20 lbs. of water per minute per horse-power, but with a good compound engine, doing regular work, it will fall to 12 to 15, and with high class triple compounds as low as 10 lbs.

The friction of the condenser tubes and the velocity of the entrance of the water is equivalent to a head of 5 to 10 feet, which must be added to the work of the pump supplying the cooling water.

The speed of this water is safely taken at 10 feet per second through the pipes, while in the navy they use 15.

and centrifugal pumps are commonly employed for this purpose, the best speed for them being 150 revolutions per minute.

The air-pump capacity in surface-condensing engines may be as low as $\frac{1}{20}$th of the low-pressure cylinder.

CHAPTER XIX.

THE POWER OF STEAM-ENGINES.

THE power of engines is universally stated in comparison with that of horses, and the English standard is the maximum work of which a powerful horse is found to be capable, viz.: 33,000 lbs. raised 1 foot high in 1 minute.

As a matter of practice this result is unattainable with ordinary animals for any length of time, therefore a steam-engine of given effective power is equal to more than the work of the number of horses stated.

An effective horse-power, called also, brake, belt, or actual horse-power, is the real power given by it from the shaft, pulley, or belt.

An indicated horse-power is the power developed by the steam in the cylinder, and of course from it has to be deducted the power eaten up in driving the engine itself.

The French "force de cheval" is a close approximation to the English, as,

1 English horse-power = 1.01385 force de cheval.

Inversely stated—

1 Force de cheval = .986337 of an English horse-power.

The rule for finding a *French indicated horse-power* is as follows:

Let D = diameter of cylinder in metres.
S = stroke in metres.
R = revolutions per minute.
P = average pressure on piston in kilogrammes per □ centimetre.

French indicated horse-power = $3.49 \times D^2 \times P \times R \times S$.

From the result of above deduct 15 to 20 per cent. to arrive at approximate effective horse-power.

The rule for ascertaining the *English indicated horse-power* of an engine is,

A = area of piston in square inches. (See Table of Areas, p. 42.)
S = stroke in feet (not inches).
P = average pressure on piston in lbs. per square inch. (See following table.)
R = revolutions per minute.

$$\text{Indicated horse-power} = \frac{A \times P \times R \times 2S}{33{,}000 \text{ ft.-lbs.}}.$$

From which should be deducted an amount of 15 to 20 per cent. to allow for the force required to operate the engine itself. The net result is effective horse-power.

The standard of a horse-power has been adopted by other nations with fractional variations to suit their own standards of weight and measure. The differences are not large, being about 1½ per cent. at the most, and for general purposes the three following standards will be found all that are usually required :

STANDARD HORSE-POWERS OF VARIOUS NATIONS.

	English Foot-pounds per Minute.	French Kilo-gram-Metres per Minute.	Austrian Foot-pounds per Minute.
An English horse-power....... =	33,000	4,562.46	25,233.6
A French horse-power........ =	32,548.2	4,500	25,420.8
An Austrian horse-power...... =	33,034.2	4,567.14	25,800

A commercial horse-power is a term in use in America, and represents an amount of 30 lbs. of water evaporated from feed-water at a heat of 100° Fahrenheit, and raised therefrom to a pressure of 70 lbs. over the atmosphere.

This rather clumsy definition of a power forms a standard for the power or duty of boilers, which is convenient in the absence of any clearer form of reference. Naturally, with boilers working under widely different conditions, a parity can be established only by proportionate calculations, and the same remark would hold good of steam-engines using more or less than the amount it fixes as a basis.

For the purpose of readily ascertaining the power of any given engine cylinder the following table will be found to save much calculation :

TABLE OF MEAN PRESSURES OF STEAM IN CYLINDERS.

Initial Pressure per Square Inch.	AVERAGE PRESSURE OF STEAM IN LBS. PER SQUARE INCH FOR THE ENTIRE STROKE.				
	Steam Cut off at ¾ of Stroke, a wasteful amount.	Steam Cut off at ⅝, as in Ordinary Engines.	Cut-off at ½, as in good High-speed Engines.	Cut-off at ⅜, as in Condensing Engines.	Cut-off at ¼, as in very High-class Engines, or in others when Running Light.
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
5	4.8	4.6	4.2	3.7	3
10	9.6	9.2	8.4	7.4	5.9
15	14.5	13.8	12.7	11.2	8.9
20	19.3	18.4	16.9	14.8	11.9
25	24.1	22.9	21.1	18.6	14.9
30	29	27.5	25.4	22.3	17.9
35	33.8	32.1	29.6	26	20.8
40	38.6	36.7	33.8	29.7	23.8
45	43.4	41.3	38.1	33.5	26.8
50	48.3	45.9	42.3	37.2	29.8
60	57.9	55.1	50.7	44.6	35.7
70	67.6	64.3	59.2	52.1	41.7
80	77.3	73.5	67.7	59.5	47.7
90	86.9	82.7	76.1	66.9	53.6
100	96.6	91.9	84.6	74.4	59.6
110	106.2	101.1	93.1	81.8	65.6
120	115.9	110.3	101.5	89.3	71.5
130	125.6	119.4	110	96.7	77.5
140	135.2	128.6	118.5	104.1	83.4
150	144.9	137.8	126.9	111.6	89.4
160	154.6	147	135.4	119	95.4
180	173.9	165.4	152.3	133.9	107.3
200	193.2	183.8	169.2	148.8	119.2

Nominal Horse-Power.—This term is, among engineers, happily becoming obsolete, and it would not be necessary to deal with it here but for its continued use by merchants and some manufacturers in their price-lists, rendering it necessary for a purchaser to ascertain what is intended by the term. The effective horse-power may be roughly taken at 2½ to 3 times the stated nominal power of ordinary single-cylinder engines. In compound engines it may be taken at 4 times the amount, always assuming that a proper size of machine is represented by the nominal power.

The rule, if such it can be called, to produce this absurd anachronism, is as follows:

D = diameter of cylinder in inches.
S = stroke of engine in feet.

The "nominal" H. P. $= \dfrac{D^2 \times \sqrt[3]{S}}{15.6}$ for ordinary engines.

For condensing engines take,

$$\frac{D^2 \times \sqrt[3]{S}}{47}.$$

In practice, to find approximately what cylinder a nominal horse-power represents, or, rather what it *should* represent, it is necessary to fall back on a list, in which I have collected the average sizes of cylinders represented by "nominal horse-power."

The figures in the list following are what should be insisted on as the proper value for an engine of a given nominal power, when comparing prices:

AVERAGE SIZES OF CYLINDERS CORRESPONDING TO VARIOUS NOMINAL HORSE-POWERS IN VARIOUS TYPES OF ENGINES.

Nominal Powers.	Single Cylinder, Vertical.	Single Cylinder, Horizontal.	Single Cylinder, Condensing.	Portable Engines or Semi-Portable.	Double Compound, Horizontal.	Vertical Double Compound pattern, for Mill Work.	Vertical Triple Compound, for Mill Work.
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
2	4 × 6	4 × 7	......	......	......	......	......
2½	4½ × 8	5 × 8	......	5 × 8	......	......	......
3	5½ × 8	6 × 8	......	6 × 9	......	......	......
4	6¼ × 9	6½ × 10	6½ × 12	6¾ × 10	......	......	......
5	7 × 11	7 × 10	......	7½ × 10	......	4½&7¾ × 5	......
6	8 × 12	7½ × 12	8 × 16	8¼ × 12	......	5½&9 × 6	......
7	8½ × 10	8 × 14	......	8¾ × 12	......	......	......
8	9 × 13	9 × 16	9 × 18	9½ × 12	6½ & {10, 12} × 14	6 & 10½ × 8	......
10	10 × 14	10 × {16, 18}	10 × 20	10½ × 14	7 & 12½ × 14	7½ & 13 × 9	......
12	11 × 14	11 × {20, 22}	11½ × 20	11½ × 16	8 & 14 × 16	8½&14½ × 10	......
14	12 × 16	12 × {20, 24}	12 × 24	Dbl. cyl. 2–8¾ × 12	8½ & 15 × 16	9 & 18 × 18	......
15	13 × 16	......	12 × 26	2–9 × 12	......	......	......
16	......	13 × {20, 27}	13 × 24	2–9½ × 14	9 & 16 × 18	10 & 20 × 18	......
18	14½ × 20	{14 × 24, 14½ × 20}	13½ × 24	......	......	......	......
20	15 × {18, 20}	14½ × {24, 30}	14½ × 28	2–10½ × 14	10 & 18 × 21	11 & 22 × 21	......
23	......	15½ × 28	15 × 28	......	......	......	......
25	16 × 20	16 × 28	16 × 28	2–11½ × 16	12 & 21 × 24	12 & 24 × 21	......
26	......	16 × 33	16 × 33	......	......	......	......
28	......	......	......	......	......	13 & 26 × 24	
30	......	17½ × 36	17½ × 36	2–12½ × 18	13 & 22 × 24	......	10 & 16 & 26 × 18
33	......	18 × 33	18 × 33	......	......	14 & 28 × 24	......
35	......	19 × 36	18 × 36	......	14 & 24 × 24	......	......
38	......	......	19 × 36	......	......	15 & 30 × 24	......
40	......	20 × 40	20 × 40	2–14 × 18	......	......	11 & 17 & 28 × 21
43	......	......	20 × 42	......	......	16 & 32 × 24	......
45	......	......	......	......	15 & 26 × 30	......	......
48	......	......	......	......	......	17 & 34 × 27	......
50	......	22½ × 40	22 × 42	2–16 × 18	......	......	12 & 20 & 32 × 24
55	......	......	......	......	16 & 28 × 36	18 & 36 × 27	......
60	......	24½ × 44	......	......	......	19 & 38 × 30	13 & 22 & 35 × 27
65	......	......	......	......	17 & 30 × 39	20 & 40 × 30	......
70 or 72	......	28 × 50	......	......	......	21 & 42 × 30	14&23½&37½ × 27
80	......	......	......	......	......	22 & 44 × 33	15 & 25 & 40 × 27
100	......	......	......	......	......	25 & 50 × 36	16½ &27½&44 × 30
120	......	......	......	......	......	27 & 54 × 36	18 & 30 & 48 × 33
150	......	......	......	......	......	30 & 60 × 39	19½ & 32 & 52 × 33

These figures have been prepared from the nominal horse-powers given by first-class manufacturers, but it must be borne in mind that a common practice with mer-

chants is to alter the nominal powers so as to supply a smaller engine for a given power, establishing a higher rate of speed to make up the difference.

Thus, one list may be found to give for a compound engine of 20 nominal horse-power cylinders 10″ and 18″ × 21″ stroke at 90 revolutions and 80 lbs., while another gives only 9″ and 14″ × 16″ at 135 revolutions and 100 lbs., both thus offering to the user 60 indicated horse-power—needless to point out how great a difference in cost exists between the two.

It will thus be seen how unreliable a factor is the mere statement of a nominal horse-power to the purchaser of an engine.

While the preceding table may be found of use in comparing the first costs of various steam-engines from price-lists, the work to be done by them should be accepted only upon calculation of the indicated horse-power due to *size, speed, and mean steam pressure.*

These are, in the succeeding chapters, tabulated for all ordinary commercial sizes and considered in the following order:

A. Vertical patterns.
B. Horizonal patterns.
C. The portable and semi-portable engine.
D. Special types of high-speed engines.

CHAPTER XX.

VERTICAL ENGINES.

THE vertical engine, or, as it should more properly be called, the "inverted engine," is arranged with its cylinder on a standard, or frame-work, over the crank-shaft, in which position it occupies little floor space, and is very handy of access if well designed. For very many purposes of small motive power it is the most handy and useful engine, and it is quite the cheapest form of first motive power as regards first cost. The chief fault of the vertical engine is, that it is not so free from vibration as the horizontal pattern, but if its construction be of a solid character this objection disappears.

In many cheap patterns the glands are very difficult of access and the lubricating arrangements are ineffective. These points should be looked to in purchasing.

A distinct advantage of the vertical engine is the even wear of the cylinder, there being no tendency to wear oval, as in the horizontal, due to the weight of the piston.

The dead weight of the working parts is also freely supported on the crank-pin, and these two features should make a vertical engine under exactly similar conditions more economical than a horizontal pattern. In practice, however, the difference is inappreciable, and the adoption of one pattern or other is to be decided by convenience.

The small vertical engine may be made portable at very moderate expense. Its wastefulness of fuel is due to the poor design of the vertical boilers commonly supplied with

it for the sake of economy in first cost, and in space occupied.

As a set-off to this an arrangement should always be insisted upon whereby the feed-water is heated to some extent.

This can be conveniently accomplished by having the bed-plate on which either engine or boiler, or sometimes both together, stand, made hollow and arranged to act as a tank or hot well, the contents being warmed by part of the exhaust steam from the engine. The whole of the exhaust cannot be condensed, as in these little boilers the bulk of the steam is usually needed to be turned up the chimney to create a draught for the fire.

The commercial vertical engine is not to be recommended as a motor when exceeding a cylinder of 10 inches diameter, although manufactured by some firms up to 15 inches bore.

Some firms still continue to manufacture vertical engines attached to the shell of vertical boilers. This is not an advantageous method, throwing strains on to the shell which it is not suited to bear, and the only possible economic advantage that can be seen about the arrangement, besides cheapness, is that the vibrations of the engine are communicated to the water and thus aid the separation of the steam bubbles.

For very small powers, however, the arrangement would be open to no serious objection, provided the engine is mounted on a complete plate without a riveted or welded joint between the working parts either in line or across it.

Some capital small compound vertical engines are now being put on the market of as small powers as 2 and 3 nominal horse-power.

The prices of these, complete with boiler and water-heater base-tank, are £65, or $325, and £83, or $415, respectively.

Dynamo-Driving.—A very commendable use of the vertical engine, which is rapidly extending at present, is for the purpose of driving dynamos, and such fast-running machines as centrifugal pumps and fans, either directly attached to its crank-shaft or by one belt.

The following is a list of suitable proportions for the engines destined for this special work, which is now of such growing importance and wide-spread use as to demand special consideration among applications of power.

TABLE OF SINGLE-CYLINDER HIGH-SPEED VERTICAL OR HORIZONTAL ENGINES SUITED FOR COUPLING DIRECT TO A DYNAMO, WITH POWERS AND PRICES OF BOTH ENGINE AND RELATIVE DYNAMO.

Indicated Horse-Power.	Cylinder.			Boiler Pressure per Square Inch.	Dynamo.		Prices, Vertical or Horizontal.		Space occupied when Vertical Engine. All in Ins.			Space occupied when Horizontal Engine. All in Ins.		
	Bore.	Stroke.	Revolutions.		Size in Units of 1000 Watts.	No. of 16 Candle Lamps.	Engine only.	Engine and Dynamo Combined.	Long.	Wide.	High.	Long.	Wide.	High.
	Ins.	Ins.	No.	Lbs										
5½	5	4	400	80	4	40	....	£125=$625	48	30	57	48	48	36
6	5½	5	200	80	5	25	£42=$210	£130=$650	58	32	63	102	30	34
9	5½	5	300	80	5	38	" "	" "	"		"	"		"
12	5½	5	400	80	5	50	" "	" "	"		"	"		"
10½	6½	6	200	80	6	41	£52=$260	£165=$825	69	37	76	108	36	42
13	6½	6	250	80	6	48	" "	" "	"		"	"		"
16	6½	6	300	80	6	65	" "	" "	"		"	"		"
18	6½	6	350	80	6	75	" "	" "	"		"	"		"
16	7½	7	200	80	7	65	£58=$290	£210=$1,050	74	38	93	"		"
20	7½	7	250	80	7	80	" "	" "	"		"	"		"
25	7½	7	300	80	7	95	" "	" "	"		"	"		"
29	7½	7	350	80	7	110	" "	" "	"		"	"		"
16	8½	8	150	80	8	65	£62=$310	£240=$1,200	80	40	78	128	40	50
21	8½	8	200	80	8	85	" "	" "	"		"	"		"
27	8½	8	250	80	8	110	" "	" "	"		"	"		"
32	8½	8	300	80	8	150	" "	" "	"		"	"		"
37	8½	8	350	80	9	200	" "	£275=$1,375	"		"	"		"
23	9½	9	150	80	9	90	£78=$390	£287=$1,435	98	48	104	140	48	58
30	9½	9	200	80	9	120	" "	" "	"		"	"		"
36	9½	9	250	80	11	200	" "	£305=$1,525	"		"	"		"
46	9½	9	300	80	11	230	" "	" "	"		"	"		"
30	10½	10	150	80	11	140	£98=$490	£360=$1,800	105	53	112	156	54	68
40	10½	10	200	80	12	190	" "	£380=$1,900	"		"	"		"
50	10½	10	255	80	12	250	" "	" "	"		"	"		"
60	10½	10	300	80	12	300	" "	" "	"		"	"		"

For small powers, a single-cylinder engine may be employed, standing upon an extension of the dynamo bed-plate.

Engines specially designed for this purpose are made by most of the large agricultural engineers and also by many of the high class engine-builders of the United States and England, and for confined spaces, especially on board ship, these machines leave little to be desired.

In this direct driving it must be clearly borne in mind that a very high rate of speed is necessary for the engine, as otherwise the size of the dynamo has to be increased and the first cost runs up excessively. Therefore the ordinary commercial vertical engine will not do for this work, as greater rigidity, shorter stroke, and better special lubricating arrangements are a necessity for the duty.

The high speed at which these direct coupled engines are run renders them uneconomical as regards their consumption of steam, and it would not be safe to assume that they would absorb less than about 40 lbs. per indicated horse-power per hour.

When, therefore, this is taken into consideration, together with the extra dimensions of a dynamo required to give the electrical output at what is to the latter a slow speed, it will be evident that direct coupled engines are not to be considered advisable unless space is of primary importance.

Vertical engines are well adapted to the driving of dynamos by a belt, connecting a fly-wheel or belt-pulley to the dynamo pulley. For such an arrangement, a high speed of rotation is still necessary for the engine, but a little longer proportion of stroke is permissible and advantageous, while a much smaller dynamo can be utilized, giving an equal output at a much higher rate of speed, and the whole arrangement thus becomes cheaper in first cost.

The two machines can be very compactly arranged, as will be seen by the two succeeding lists of combination plants.

VERTICAL ENGINES DRIVING DYNAMOS BY BELT ON ONE BED-PLATE.

Effective Horse-Power.	Size of Engine.	Revolutions per Minute.	Pressure.	Floor Space Occupied.	Units of Dynamo.	Speed of Dynamo per Minute.	Maximum Number of 16 c.-p. 55-Watt Lamps.
			Lbs.		Watts.		
6.4	5" × 6"	270	80	3' 4" × 3' 4"	4,000	1,480	70
9.5	5½ × 6	336	80	3 4 × 3 4	6,000	1,400	106
15.4	7 × 7	302	80	4 6 × 4 0	10,000	1,370	181
24.4	7½ × 8	345	80	5 0 × 4 0	16,000	1,200	282
30.2	8 × 8	376	80	5 0 × 4 0	20,000	1,000	353
37.3	9 × 9	320	80	5 6 × 4 0	25,000	925	441
44.8	10 × 12	233	80	5 6 × 4 6	30.000	825	529
59.1	11 × 12	253	80	6 0 × 4 6	40,000	750	705
73.7	12 × 12	265	80	6 0 × 5 0	50,000	680	900

The above being extremely compact, the belt must necessarily be very short, and a little more space in the direction of its length is advisable if possible, such as shown by another set of sizes, driven at more moderate speeds, as follows :

VERTICAL ENGINES, MODERATE SPEED, DRIVING DYNAMOS BY BELT ON ONE BED-PLATE.

Effective Horse-Power.	Size of Engine.	Revolutions per Minute.	Pressure.	Floor Space Occupied. Inches.	Units of Dynamo.	Speed of Dynamo per Minute.	Number of 16 c.-p. 55-Watt Lamps in Regular Use.
			Lbs.	long wide high	Watts.		
6.5	5½" × 8"	260	80	110 × 30 × 61	3,500	1,500	60
9.25	6½ × 10	210	80	110 × 36 × 77	5,000	1,440	85
12.25	7½ × 10	210	80	110 × 36 × 80	6,000	1,400	100
14	8 × 12	175	80	110 × 39 × 85	9,000	1,385	150
17.5	9 × 12	175	80	140 × 48 × 99	10,000	1,370	175
22	10 × 14	150	80	140 × 54 × 108	12,000	1,300	200

A table of sizes and powers of these small engines under various speeds and pressures, which follows, will be found useful for reference and decision in this connection :

TABLE OF EFFECTIVE POWERS OF VERTICAL HIGH-SPEED ENGINES AT VARYING STEAM-PRESSURES AND SPEEDS.

Steam Pressure per Square Inch.	Size of Engine Cylinder × Stroke.																														
	5″ × 4″					6″ × 5″					7″ × 6″				8″ × 7″					9″ × 8″				10″ × 9″				12″ × 10″			
	Revolutions per Minute.																														
	200	250	300	350	400	200	250	300	350	400	200	250	300	350	150	200	250	300	350	150	200	250	300	150	200	250	300	150	200	250	300
	Horse-Power.																														
Lbs. 30	1¼	1½	1¾	2	2½	2¼	2¾	3¼	3¾	4¼	3½	4½	5¼	6	4	5½	6¾	8	9½	5¾	7¾	9½	11½	8	10½	13	16	13	16	21	25
40	1¾	2	2½	2¾	3	2¾	3½	4¼	5	5¾	4½	5¼	6¾	8	5¼	7	9	10½	12	7½	10	13	15	10	14	18	21	17	23	29	34
50	2	2½	3	3½	4	3½	4½	5½	6½	7½	5¾	7½	8¾	10	7	9	11½	14	16	10	13	16	20	14	18	23	27	22	29	37	44
60	2½	3	3½	4	4½	4½	5½	6½	7½	8½	7	8¾	10	12	8	11	13	16	19	11½	15½	19	23	16	21	26	32	26	34	42	50
70	3	3½	4	4¾	5½	5	6¼	7½	8¾	10	8	10	12	14	9	12½	15½	18½	21½	13	18	22	26	18	24	31	37	30	40	50	59
80	3¼	4	4¾	5½	6½	5½	7	8½	10	11¼	9	11	13½	16	10	14	18	21	24	15	20	26	30	20	28	36	42	34	46	58	68
90	3½	4½	5¼	6¼	7	6¼	8	9½	11	12¾	10	12½	15	17½	12	16	20½	24½	28	17	23	29	35	24	32	41	48	39	52	65	79
100	4¼	5¼	6¼	7½	8½	7	9	10½	12½	14	11½	14½	17	20	14	18	23	28	32	20	26	32	40	28	36	46	54	44	58	74	88

Most Economical Loads.—The above table appears to be sufficiently comprehensive for all powers up to nearly 90 effective horse-power, but it is usefully supplemented by a table drawing a comparison between these maximum effective powers and the most economical load, which is a point frequently lost sight of :

Size of Cylinder.		Ordinary Revolutions per Minute.	Effective Horse-Power at Boiler Pressures of						Maximum Revolutions per Minute, suited for Electric Work.	Effective Horse-Power at Boiler Pressures of					
			60 Lbs.		80 Lbs.		100 Lbs.			60 Lbs.		80 Lbs.		100 Lbs.	
Diam.	Stroke.		Economical Load.	Maximum Load.	Economical Load.	Maximum Load.	Economical Load.	Maximum Load.		Economical Load.	Maximum Load.	Economical Load.	Maximum Load.	Economical Load.	Maximum Load.
4½″	8″	190	2¼	3¼	3¼	4	3½	7	260	3¼	4½	4½	5½	5	6½
5½	8	190	3¼	5¼	4½	6½	4½	8¼	260	4½	7¼	6½	9	7½	10
6½	10	168	5¼	8	7¼	10	5½	11	210	6¾	10	9¼	12	10½	14
7½	10	168	7¼	10	9½	13½	11	15	210	9	13	12¼	17	13¾	19
8	12	140	8	12	11	15	12½	16½	175	10	15	14	19	16	21
9	12	140	10¼	15	14	19	16	21½	175	13	19	17½	24	20	26
10	14	120	12½	19	17½	24	20	26¼	150	16	24	22	30	25	33
11	14	120	15½	23	21	28½	24¼	32	150	19½	29	26½	36	30½	40
12	16	105	18¼	27	25	34½	28½	38¼	130	23	34	31½	43	36	48
13	16	105	21½	32½	29	40	33½	44½	130	27	41	36½	50	42	56
14½	20	85	28	42¼	39	54	44	60	105	35	53	49	67½	55	75
16	20	85	34½	52	47½	65	52½	72	105	43	65	59½	81½	66	90

Any of these single engines may be coupled to another of same size, preferably with cranks set at right angles to one another, and will then give off an increased power, equal to nearly double the power of the single engine.

Such double engines are supplied in the same sizes as single engines, and are largely used for driving dynamos direct in ship-work of a high class.

They cost somewhat more than the bare price of two single machines.

A particular advantage of a double engine over a single is some gain in regularity of turning. There is practically no other economy, and thus, when the cost of a double engine comes to be considered, it is open to question if the

amount of extra cost needed to make it of compounding proportions should not be incurred.

Such small high-speed compound engines are made in infinite varieties of sizes to suit the exact conditions of their work.

COST OF DOUBLE CYLINDER VERTICAL ENGINES.

		Price of Single Engine.
Double engines having two $6\frac{1}{2}'' \times 6''$ cylinders	£120= $600	£52 = $260
" " " " $8\frac{1}{2} \times 8$ "	£155= $775	£62 = $310
" " " " $9\frac{1}{2} \times 9$ "	£180= $900	£78 = $390
" " " " 10×8 "	£207=$1,035	£87 = $435
" " " " $10\frac{1}{2} \times 10$ "	£220=$1,100	£98 = $490
" " " " 11×10 "	£282=$1,410	£98 = $490

They are made for marine work, as launch engines, with shorter strokes than the above, and are then suited for coupling direct to dynamos, fans, and centrifugal pumps, as follows:

DOUBLE-CYLINDER VERTICAL ENGINES—SHORT STROKE AND HIGH SPEEDS.

Maximum Indicated Horse-Power.	CYLINDERS—TWO OF		Revolutions per Minute.	Pressure per Square Inch.	Cost.
	Diameter, Inches.	Stroke, Inches.			
6	3	3	400	100 lbs.	£58= $290
12	4	3	400	100 "	£64= $320
20	5	4	350	100 "	£74= $370
30	6	4	350	100 "	£92= $460
40	7	5	280	100 "	£110= $550
50	8	5	280	100 "	£136= $680
70	9	6	250	100 "	£180= $900
90	10	6	250	100 "	£210=$1,050

For the purpose of comparison, the following may be useful:

HIGH-SPEED DOUBLE-COMPOUND NON-CONDENSING ENGINES.

Maximum E. H. P.	Cylinders. High Pressure. Inches.	Cylinders. Low. Pressure. Inches.	Stroke, Inches.	Revolutions per Minute.	Boiler Pressure per Square Inch.	Cost of Engine.
8	4	7	5	350	100 lbs.	£128= $640
	4½	7¾	5	300	100 "	£140= $700
15	5	9	6	300	100 "	£157= $785
25	6	11	7	300	100 "	£189= $945
	6	10½	8	275	100 "	£189= $945
34	6⅜	10⅝	7	285	100 "	£170= $850
	7	13	8	250	100 "	£230=$1,150
50	7½	12½	8	250	100 "	£247=$1,235
	8½	14¾	10	200	100 "	£270=$1,350
75	9	15	10	217	100 "	£282=$1,410
106	11	18¼	12	200	120 "	£412=$2,060
169	12	20	14	182	130 "	£470=$2,350
280	15	25	16	168	130 "	£648=$3,240
420	18	32	20	150	130 "	£1,170=$3,850

This brings us to the point of considering what may be regarded as the developed vertical engine, viz.:

The Double-Compound Vertical or "Marine Pattern" Engine.—The title "marine engine" is getting to be somewhat misleading, as the use of these engines is very extensive on land, where for a number of purposes they prove particularly suitable.

Wherever reversing has to be part of the engine's duties they are specially desirable, and, naturally, also where space is an object. The double and triple compound engine has shown its superior economy over the single cylinder, even apart from the process of condensing, which may or may not be adopted with either of them.

In no duty has the double-compound engine made more strides than in electric-power supply, where its short stroke, solidity, and balance of parts, and consequent ability to run regularly at a high rate of speed, make it easy to connect direct to the dynamo shaft or to drive the latter by one directly-connected belt.

Its use on land must by no means be considered to be confined to this work, for it does admirable duty as a workshop engine, also in driving blowing, ventilating, and disintegrating machinery—in a word, wherever high speed, compactness, and easy control are special objects.

It is not the most suitable engine for pumping duties, nor need its expense be contemplated for such land purposes as can be performed by a decent horizontal compound engine.

DOUBLE-COMPOUND VERTICAL CONDENSING ENGINES, WITH RESPECTIVE BOILER PROPORTIONS.

Indicated Horse-power.	Cylinders.			Revolutions.	Boiler.			
	H. P.	L. P.	Stroke.		Pressure. Lbs.	Heating Surface. Sq. Ft.	Grate Area. Sq. Ft.	
	Inches.							
7½	3	& 6	× 4	350	100	30	2.18	High speed.
10	4	& 8	× 5	350	100	40	2.76	
20	5	& 10	× 6	300	100	80	4	
35	6	& 12	× 8	280	100	140	7	
45	7	& 14	× 8	280	100	180	8	
65	8	& 16	× 10	240	100	260	9.5	
52	9	& 18	× 18	100	90	208	6	Average speeds.
67	10	& 20	× 18	100	90	268	7	
85	11	& 22	× 21	90	90	340	9	
102	12	& 24	× 21	90	90	408	11	
128	13	& 26	× 24	85	90	512	13	
148	14	& 28	× 24	85	90	592	15	
171	15	& 30	× 24	85	90	684	17	
193	16	& 32	× 24	85	90	772	20	
233	17	& 34	× 27	80	90	932	24	
258	18	& 36	× 27	80	90	1,032	26	
300	19	& 38	× 30	75	90	1,200	32	
333	20	& 40	× 30	75	90	1,332	34	
368	21	& 42	× 30	75	90	1,472	37	
416	22	& 44	× 33	70	90	1,664	42	
454	23	& 46	× 33	70	90	1,816	46	
488	24	& 48	× 33	70	90	1,952	49	
542	25	& 50	× 36	65	90	2,168	55	
588	26	& 52	× 36	65	90	2,352	59	
635	27	& 54	× 36	65	90	2,540	64	
680	28	& 56	× 39	60	90	2,720	70	
730	29	& 58	× 39	60	90	2,920	74	
780	30	& 60	× 39	60	90	3,120	80	

EFFECTIVE POWERS OF VERTICAL DOUBLE-COMPOUND NON-CONDENSING ENGINES AT VARIOUS STEAM PRESSURES AND SPEEDS.

Steam Pressure.	Revolutions per Minute.																			
	150	200	250	300	350	150	200	250	300	350	150	200	250	300	350	150	200	250	300	350
	4″ & 7″ × 5″ Stroke.					5″ & 9″ × 6″ Stroke.					6″ & 11″ × 7″ Stroke.					7″ & 13″ × 8″ Stroke.				
Lbs. 80	2¾	3¾	4¾	5¾	6½	5	7	8½	10	13	9½	12½	16	19	21	16	20	26	32	37
90	3¼	4¾	5¾	6¾	7½	6¼	8½	10	12	15	11	14	18	21	25	18	23	30	36	42
100	3¾	5¼	6½	7¾	8½	7¼	9¾	12	15	17	12	17	21	25	29	20	27	34	41	47
110	4½	5¾	7¼	8¾	9¾	8¼	11	14	17	19	13	19	23	28	33	22	30	38	45	52
120	5	6	8	9½	11	9	12	15	18	21	15	21	26	31	36	25	33	41	51	57
130	5¼	6½	8¾	10	12	10	14	17	20	23	17	23	29	34	40	27	36	45	56	63
140	5¾	7	9¾	11	13	11	15	19	22	25	18	25	31	37	44	30	40	50	60	70
150	6¼	7½	10½	12	14	12	17	20	23	27	20	27	34	40	47	33	43	55	65	75
160	6¾	8	11	12¾	15	13	18	22	25	29	21	29	36	44	51	35	46	58	70	80
	8″ & 14″ × 9″ Stroke.					10″ & 16″ × 10″ Stroke.					11″ & 18½″ × 10″ Stroke.					12″ & 22″ × 12″ Stroke.				
Lbs. 80	19	27	32	40	45	31	41	51	61	71	40	49	62	74	86	63	83	105	125	145
90	24	32	40	48	55	36	48	58	72	84	45	58	73	87	102	75	100	125	150	175
100	27	36	46	53	62	41	55	69	82	95	52	66	83	100	115	84	114	142	170	200
110	30	40	50	59	70	46	62	76	92	110	60	74	94	112	131	96	130	160	193	220
120	34	45	57	65	78	51	70	86	103	120	70	83	104	124	145	106	142	175	212	250
130	37	48	61	72	85	56	75	95	111	132	75	90	112	135	158	114	156	192	232	270
140	40	53	65	80	93	61	82	102	123	142	82	100	124	146	175	125	170	210	245	300
150	44	58	72	85	98	66	88	110	135	155	90	108	135	158	190	137	185	230	270	320
160	48	63	80	90	108	71	95	120	143	165	95	116	146	168	204	147	200	250	295	350

The preceding table of effective powers of double compound engines of very usual proportions, each under nine different initial pressures and five different rates of speed, will be found comprehensive from three to three hundred horse-power, and for guidance as to powers in excess of this amount a further list is added on p. 144 of sizes up to nearly 800 horse-power.

The Triple-Compound Engine.—This type of engine has now conclusively established its hold upon marine practice. Its practical economy over even good double-compound engines has been demonstrated, and has in certain cases exceeded 20 per cent.

This is probably largely due to an increase in ease of turning, owing to the three cranks employed, but the higher pressures of which the machine makes economical use, would alone sufficiently justify the use of the system for mill-work. The pressure most widely adopted is 160 to 170 lbs. per square inch, the cylinders making successive use of it, till it is reduced to about 5 lbs. per square inch below the atmosphere.

Almost necessarily, surface condensation is adopted with these engines, the results of which are so well substantiated by practice as to recommend that form of condenser specially to a mill owner, although there are other good adaptations of jet or other condensers to this type of engine. In dealing with the tri-compound engine, it is taken for granted that condensation is adopted as a matter of course.

Proportions of Cylinders.—The relative proportions of the three cylinders depend upon the steam pressure, and upon the work to be done.

It will not be economical to cut the economy too fine in any direction. Too early a cut-off induces excessive condensation in the cylinders—the proportion of cylinders must as far as possible be arranged to equalize the strain on each crank. Yet variations in the duty and consequent

steam-supply have to be allowed for, although this need not affect the resultant economy to any great extent. The following are good and usual proportions :

Boiler Pressure per Square Inch.	High-Pressure Cylinder.	Intermediate Cylinder.	Low-Pressure Cylinder.
140	1	2.40	5.85
150	1	2.55	6.90
160	1	2.70	7.25

The following list of triple-compound engines ranges from 8 indicated horse-power to 800, and while the first eight sizes are suited to the high-speed direct-driving of machinery, the remaining engines are specially proportioned for mill work, or equally well for electric installations, which they drive well by means of rope gearing.

TRIPLE-COMPOUND OR TRIPLE-EXPANSION ENGINES FOR MILL WORK.

Cylinders.			Stroke.	Revolutions per Minute.	I. H.-P. Economical Load.	I. H.-P. Maximum Load.
High.	Intermediate.	Low.				
Inches.	Inches.	Inches.	Inches.			
3	5	8	4	350	8	10
4	6½	10½	4	350	13	17
5	8	13	6	300	25	33
6	10	16	6	300	40	50
7	11½	18½	8	280	64	80
8	13	21	8	280	80	108
9	15	24	10	240	100	151
10	16	26	18	120	150	180
11	17	28	21	100	200	240
12	20	32	24	90	250	300
13	22	35	27	85	300	360
14	23½	37½	27	85	350	420
15	25	40	27	85	400	480
15½	26	41½	30	80	450	540
16½	27½	44	30	80	500	600
17	28½	45½	33	75	550	660
18	30	48	33	75	600	720
19	32	51	33	75	700	840
20	33½	53½	36	70	800	960

We reach in this machine a pitch of considerable advance toward the best possible results with steam driving, which, until the quadruple-engine has demonstrated serious superior advantages, may be regarded as the best attainable.

Circulating Water.—The amount of circulating water required to be passed or pumped over the condensing tubes in these engines may be taken at 10 lbs. weight, or 1 imperial gallon, per indicated horse-power developed.

CHAPTER XXI.

SPECIAL TYPES OF STEAM-ENGINES.

UNDER this heading might be classed a large number of very meritorious high-speed machines, which would require a large amount of space fully to describe. They are of what are known as "closed" patterns as regards the design, and single-acting, that is, employing steam on one side of the piston only as regards the use of the steam.

A few representative forms of American and English practice are here discussed.

These special closed engines are made with one, two, or three cylinders, arranged in line over the crank-shaft, and in this form may be properly classed as vertical engines. The impulse is only on one side of the pistons, but in one form, by an ingenious adaptation of a closed air-cylinder below, a return spring or effort is obtained, due to the expansion of the air, which has been compressed by a plunger on the down stroke. This serves the further purpose of making the turn over the dead-centre easy and quiet by an equalization of force on the crank-pin equivalent to the result produced by the "lead" of the valve in a steam cylinder, but with better and simpler effect.

Engines of this pattern, made tri-compound, have given remarkably high results as regards economy, while in ease and quietude of turning they leave little to be desired. They will run for great lengths of time without stop or hitch, continuous runs of several months' duration, without any cessation whatever, having been recorded.

They are of very simple design, with the working parts readily accessible, a feature of special merit. They are also

entirely self-contained, and the crank and connecting-rod are generally arranged to run in a closed bath of oil.

The following list of sizes and powers will give a good idea of the compactness of these special types:

COMPOUND ENGINES OF CLOSED SINGLE-ACTING PATTERN.

Indicated H.-P. at 100 Lbs. Pressure.		Diameter of Cylinders.				Space Occupied by Engine, including Fly-Wheel.				
Non-Condensing.	Condensing.	High.	Low.	Stroke.	Revolutions per Minute.	Length.	Width.	Height.	Height from Base to Centre of Shaft.	Total Weight of Engine in Lbs.
11	14	$5\frac{1}{2}''$	$9''$	$5''$	450	4' 4"	2' 3"	3' 1"	11"	1,350
17	22	$6\frac{1}{2}$	11	6	400	5 3	2 6	3 7	12	2,200
27	35	$7\frac{1}{2}$	13	7	390	6 0	2 9	4 1	13	3,200
40	52	$8\frac{1}{2}$	15	8	375	6 9	3 0	4 7	14	4,400
54	70	10	17	9	350	7 6	3 6	5 2	$15\frac{1}{2}$	5,500
70	90	11	19	10	325	8 4	4 0	5 8	17	7,400
81	105	12	20	11	310	9 3	4 6	6 2	18	9,300
104	135	13	22	12	300	10 1	5 0	6 10	$19\frac{1}{2}$	11,000
129	168	14	24	13	290	10 9	5 6	7 4	21	12,500
155	201	15	26	14	275	11 6	6 0	7 10	$22\frac{1}{2}$	15,000
182	236	16	28	15	260	12 0	6 6	8 8	24	18,000
214	278	18	30	16	250	12 6	7 0	9 2	26	21,000

Another of this class of engine is made with the three cylinders set at angles to each other and operating the same crank. It has proved itself a wonderfully efficient motor for very high speeds, especially for dynamo-driving and the direct operation of fans for ship work.

It may, from its compactness and the high speed at which it may be run, be employed in places where an ordinary engine cannot be made use of, and it is also made compound with success.

In all these engines the continuous thrust on the crank-pin in one direction, and the high cushioning and easy lubrication, are great advantages for high speed, and remarkable rates of rotation are attained. Another special

form has cylinders revolving round a fixed crank, and runs as high as 2,000 revolutions per minute, while a machine known as the steam-turbine, which, as its name implies, is not, correctly speaking, what is known by the commonly accepted definition of a steam-engine, is capable of running at the enormous speed of 18,000 revolutions per minute.

In the United States, also, remarkably high rates of speed have been attained with some of these special engines.

But for all purposes, except special driving of very high-speed machinery, their adoption should not be decided upon except after careful investigation of their steam consumption.

CHAPTER XXII.

THE HORIZONTAL ENGINE.

It is in the horizontal form that the steam-engine has taken the largest hold upon industrial applications. The solidity and accessibility of the arrangement are manifest to the most untechnical observer.

It offers no obstruction to the adoption of any length of stroke, while for easy arrangement of working parts it is equally available.

Its one disadvantage in comparison with the vertical type is the wear of the cylinder due to the weight of the piston sliding upon it. This, however, may be provided for easily by a proper proportion of working parts. Wide pistons should be insisted upon, there being no definite rule for the proportion to cylinder bores, which vary very much.

A good wide proportion is ⅓ of the bore up to 16 inches diameter. The piston should contain good wide rings of cast-iron, or what are known as "Ramsbottom" steel rings, ⅜ of an inch wide in cylinders under 15 inches diameter.

Under this class come the well-known portable and semi-portable engines, combined with respective boilers, and admirably adapted to temporary installations of power.

As regards the advisability of a choice between a horizontal and a vertical engine, the preference should be given to the former, except when space is too restricted for a horizontal machine, or when the work involves direct coupling of the engine to its work, such as to dynamos, pumps, and fans.

The following are the subdivisions of the forms of horizontal engines :

1. As regards stroke—short, medium, or long strokes.

2. As to cylinders—single cylinders, twin cylinder, double compound, or triple compound.

3. Whether fixed or portable.

Short Strokes are suited for small powers, also for electric driving, which should always be as direct as possible, that is, either coupled direct to the dynamo or driving it by one belt off the engine crank-shaft. For spinning mills, where a high and uniform rate of speed is required, engines with short strokes are adapted.

Medium Strokes.—This is the via media, the happy medium which suits any conditions not covered by the previous and following considerations.

Long Strokes.—By this term is implied a stroke exceeding double the bore of cylinder. The special advantage of a long stroke is in reducing the wear and tear and loss of steam in the clearance spaces due to frequent reciprocations. With proportionately long connecting rods there is no greater internal strain on the framing or working parts.

Therefore, for all hard mill-work, saw-mills, and machine shops, wherever a large number of machines require driving by one engine with variations in power, the horizontal engine with a long stroke should be selected, and if the first-cost can by any means be incurred it should be fitted with automatic or variable expansion valve-gear.

Single Cylinder Horizontal Engines.—The proportions in which these are manufactured are very numerous, and no difficulty will be found by a purchaser in selecting one to meet his requirements.

The choice of proportion of stroke to bore has already been dealt with, and in the subjoined list will be found power and speeds corresponding.

The chief types of single-cylinder horizontal engines are those with flat bedplates and those with the "Bayonet" form of framing, sometimes known as the "Corliss." These

Bayonet-frame engines may be obtained right or left-handed and in great variety of size.

The essential difference between them and the flat bed-plate type is that in the former the cylinder is secured by its front flange to the frame, and thus in some sort is 'over-hung,' while in the latter it is resting on the bedplate. The American design of high-speed horizontal, which finds much favor for electric driving, aims at arranging a frame that will be in the direct line of strain between cylinder and crank-shaft. For this reason the bed-frame is frequently double and consequently extremely rigid and solid. The type is gradually finding its way into English designs.

HIGH-SPEED AND SHORT-STROKE HORIZONTAL ENGINES SUITED FOR DIRECT DRIVING.

Cylinder.		Cost.	Effective Horse-Power at 80 Lbs. Pressure at Various Revolutions per Minute.					
Bore in Inches.	Stroke in Inches.		150	200	250	300	350	400
5	4	£44=$220	....	3.25	4	4.75	5.5	6.5
5½	5	£46=$230	....	4.8	6	7.2	8.4	9.6
6	5	£48=$240	....	5.5	7	8.5	10	11.25
6½	6	£52=$260	....	8.4	10.4	12.8	14.4	....
7	6	£55=$275	....	9	11	13.5	16	....
7½	7	£58=$290	....	12.8	16	20	23.2	....
8	7	£60=$300	10	14	18	21	24	....
8½	8	£62=$310	12.8	16.8	21.6	25.6	29.6	....
9	8	£70=$350	15	20	26	30	....	....
9½	9	£78=$390	18.4	24	28.8	36.8	....	....
10	9	£88=$440	20	28	36	42	....	....
10½	10	£98=$490	24	32	40	48	....	....
12	10	£120=$600	34	46	58	68	....	....

The medium is struck by the adaptation of the bayonet frame and a support under the cylinder, which is usual in large high-class engines. The support is arranged with a planed slide, so that the cylinder may expand and contract upon it.

For small engines an excellent type of frame is that with self-contained double bearings, one on either side of the double-crank. Where the machine exceeds a size of 8-inch cylinder, the crank-shaft should be extended to allow of an additional outside bearing being used on an addition to the foundation. Small engines may be obtained arranged on a feed-tank base, with a vertical boiler, in which form they compete in price and efficiency with the combined vertical engine and boiler. The vertical boiler is not, however, an economical steam raiser.

The next class is a good horizontal model with a longer stroke, designed to run at somewhat more moderate speeds for general purposes of machine driving. Such engines are produced with most excellent details and proportions in the United States, where it is customary to fit them with automatic governing arrangements, and describe them as "automatic" engines. Solidity of parts is a strong feature possessed by the American machines, in which also much more care is bestowed upon the details of lubrication than is common in English practice. For long runs without stop at fairly high speeds these points are of great importance.

The governing arrangements in engines for such duties as require regularity under varying pressures or load, should be of a higher class than a mere ball-governor acting upon a throttle-valve.

Good American and English practice now adopts a governor acting directly upon the eccentric, one form of which is commonly known as a "fly-wheel governor."

Another good form has a slotted rocking-link secured to the end of the valve-rod, in which a die, attached to the end of the eccentric-rod, is adjusted by the governor, the weight of parts being suitably balanced.

Fitted with these or equivalent effective devices, these engines are fairly represented on the average by the following sizes :

AUTOMATIC HIGH-SPEED HORIZONTAL ENGINES.

Cylinder. Bore in Inches.	Cylinder. Stroke in Inches.	Revolutions per Minute.	Effective Horse-Power at 80 Lbs. Pressure.	Revolutions per Minute.	Effective Horse-Power at 80 Lbs. Pressure.	Floor Space Occupied.
8	12	250	25	325	40	8′ 6″ × 5′ 4″
9	12	250	30	325	45	8 6 × 5 4
9	15	200	35	260	50	10 2 × 5 10
10	15	200	45	260	60	10 2 × 5 10
11	15	200	55	260	75	10 2 × 5 10
11	18	180	60	240	85	11 10 × 6 6
12	18	180	70	240	95	11 10 × 6 6
13	18	180	85	240	110	11 10 × 6 6
13	20	160	90	220	120	13 2 × 7 4
14	20	160	100	220	135	13 2 × 7 4
15	20	160	110	220	150	13 2 × 7 6
15	24	140	120	185	160	15 8 × 8 4
16	24	140	135	185	180	15 8 × 8 4
17	24	140	150	185	200	15 8 × 8 8
18	27	125	170	165	225	18 4 × 9 8
20	27	125	200	165	265	18 4 × 10 0

For more general purposes very similar-sized engines may be obtained, suited to run at a lower speed :

MEDIUM-STROKE MODERATE-SPEED HORIZONTAL ENGINES.

Cylinder.		Cost.	Effective Horse-Power at 80 Lbs. Pressure.					
Bore in Inches.	Stroke in Inches.		Revolutions per Min.	Economical Load.	Maximum Load.	Revolutions per Min.	Economical Load.	Maximum Load.
4½	8	£31= $155	190	3.25	4	260	4.5	5.5
5½	8	£37= $185	190	4.5	6.5	260	6.5	9
6½	10	£46= $230	168	7.25	10	210	9.25	12
7½	10	£57= $285	168	9.5	13.5	210	12.25	17
8	12	£67= $335	140	11	15	175	14	19
9	12	£83= $415	140	14	19	175	17.5	24
10	14	£103= $515	120	17.5	24	150	22	30
11	14	£123= $615	120	21	28.25	150	26.5	36
12	16	£144= $720	105	25	34.5	130	31.5	43
13	16	£161= $805	105	29	40	130	36.5	50
14½	20	£231=$1,155	85	39	54	105	49	67.5
16	20	£266=$1,330	85	47.5	65	105	59.5	81.5

For a very large number of ordinary purposes, the following **Commercial Low-Speed Engines** of bayonet and flat-bed types will be found to be sufficiently economical in first cost and in working if reasonably well constructed. Those with flat-beds are commonly known as "Lancashire" patterns, and have a single crank with an out-board bearing to be secured to a separate foundation.

This may be regarded as the simplest and cheapest form of engine, and care should be exercised in seeing that sufficient wearing surfaces are provided in the bearings, connecting-rod, and slide-bars, as the proportions are not infrequently scamped for the sake of reducing the cost.

LANCASHIRE OR FLAT-BED PATTERNS OF HORIZONTAL ENGINES.

Cylinder.		Maximum Speed per Minute.	Cost.
Bore in Inches.	Stroke in Inches.		
6½	10	135	£41 = $205
7½	12	120	£55 = $275
9	16	98	£78 = $390
10	16	95	£89 = $445
11	20	85	£113 = $565
12	20	80	£132 = $660
13	20	80	£140 = $700
14	24	75	£168 = $840
14½	24	68	£184 = $920
15	28	65	£207 = $1,035
16	28	60	£221 = $1,105
18	33	55	£253 = $1,265
20	40	48	£328 = $1,640
22½	40	48	£371 = $1,855
24½	44	40	£450 = $2,250
28	50	38	£672 = $3,360

"Bayonet" pattern engines with a single crank and an outer bearing have an overhanging cylinder on a strong hollow framing arranged in the direct line of thrust between cylinder and bearing. With ordinary valve-gear and governor they are to be obtained as follows :

BAYONET PATTERN HORIZONTAL ENGINES.

Cylinder.		Maximum Speed per Minute.	Cost.
Bore in Inches.	Stroke in Inches.		
3½	7	200	£19 = $95
4½	8	180	£26 = $130
5½	10	140	£35 = $175
6½	12	120	£41 = $205
8	16	100	£65 = $325
9	18	90	£83 = $415
10	20	84	£108 = $540
11½	20	82	£118 = $590
12	24	75	£124 = $620
13	24	75	£136 = $680
14	28	65	£176 = $880
15	28	62	£189 = $945
16	28	60	£202 = $1,010

Long-stroke bayonet-pattern engines are made in higher classes of construction, provided with automatic control of steam, as follows:

BAYONET PATTERN HORIZONTAL ENGINES.—LONG STROKE.

Cylinder.		Revolutions per Minute.	Effective Horse-Power at 80 Lbs. Pressure.		Cost.
Bore in Inches.	Stroke in Inches.		Economical Load.	Maximum Load.	
11	22	96	36	48	£160 = $800
12	24	88	42	56	£180 = $900
13	27	78	48	64	£205 = $1,025
14½	30	70	60	80	£250 = $1,250
16	33	65	75	100	£310 = $1,550
17½	36	60	90	120	£365 = $1,825
19	36	60	105	140	£425 = $2,125

American practice has greatly developed this high-class "Bayonet"-frame engine, which, with the addition of special forms of valves worked on the Corliss or kindred systems, hold a very high place in excellence of manufacture and performance. They are commonly known as "Corliss"

engines, and are made in a great variety of sizes for all classes of duty.

HIGH-CLASS CORLISS OR AUTOMATIC ENGINES.
GENERAL SIZES AND POWERS.

Cylinder.		Revolutions per Minute.	Indicated Horse-Powers, with Steam at 80 Lbs. Pressure.			Floor Space, in Feet.
Bore in Inches.	Stroke in Inches.		Cut-off at one-fifth of Stroke.	Cut-off at one-fourth of Stroke.	Cut-off at one-third of Stroke.	
10	30	90	38	46	54	8 × 18
12	30	90	54	66	77	8 × 18
12	36	85	62	75	88	9 × 21
14	36	85	84	102	120	9 × 21
14	42	80	92	112	131	9 × 23
16	36	85	110	133	156	9 × 21
16	42	78	118	143	168	9 × 23
18	42	75	144	174	204	12 × 25
18	48	70	153	186	218	12 × 28
20	42	70	165	200	235	12 × 26
20	48	70	189	229	269	12 × 28
20	60	65	219	266	312	12 × 33
22	42	70	200	243	285	12 × 26
22	48	65	208	252	296	13 × 28
22	60	65	266	322	378	13 × 34
24	48	65	252	306	359	13 × 30
24	60	62	301	365	428	14 × 34
26	48	62	283	343	403	14 × 30
26	60	60	342	415	487	14 × 35
28	48	60	318	385	452	14 × 31
28	60	60	397	481	565	15 × 37
28	72	55	437	529	621	15 × 42
30	60	60	456	553	649	15 × 39
32	60	60	519	629	738	16 × 39
32	72	55	571	692	812	16 × 43
36	72	55	720	871	1,020	19 × 50

The merits of their elaborate and effective valve and governing gear could not here be discussed with propriety, and upon them depend largely their comparative cost. Such engines have long strokes, and are run at a moderate and economical number of revolutions. A comparison of the succeeding lists will afford information as to average

American and English sizes and powers at varying cut-offs, also the addition to the engine's power when a condenser is added, and the effect of compounding.

TABLE OF HORIZONTAL ENGINES, SHOWING EFFECT OF CONDENSATION.

Cylinder.		Revolutions per Minute.	Non-Condensing. Indicated Horse-Power at Boiler Pressures of				Revolutions per Minute.	With Horizontal Jet Condenser at Back End of Cylinder. Indicated Horse-Power at Boiler Pressures of			
			80 Lbs.		100 Lbs.			80 Lbs.		100 Lbs.	
Bore in Inches.	Stroke in Inches.		Economical Load.	Maximum Load.	Economical Load.	Maximum Load.		Economical Load.	Maximum Load.	Economical Load.	Maximum Load.
7	22	136	18	25	24	33	110	21½	26	25	33
8	22	136	25	33	31½	44	110	28	34½	33	43
9	24	125	32	42	40	54	100	35	43	41	54
10	24	125	40	52	49	67	100	43½	53	51	67
11	26	116	48	63	60	84	95	54	66	64	84
12	26	116	57	75	70	100	95	64	78	75	100
13	32	94	67	88	83	116	85	83	102	97	128
14½	32	94	84	110	105	145	85	104	127	121	160
16	36	84	102	134	125	176	75	125	153	146	192
18	36	84	130	170	160	225	75	158	194	186	245
20	42	72	160	210	200	280	65	200	240	230	305
22	42	72	195	255	240	335	65	240	290	280	370

TABLE OF HORIZONTAL ENGINES, SHOWING COMPOUND PROPORTIONS AND RESULTING RANGE OF POWER.

Diameter of High Pressure Cylinder in Inches.	Diameter of Low-Pressure Cylinder in Inches.	Stroke in Inches.	Revolutions per Minute.	Range of Effective Horse-Powers, Steam at 100 lbs. Pressure.
10	18	30	90	75 to 105
11	20	30	90	90 " 125
12	22	30	90	108 " 150
13	24	36	82	140 " 200
14	26	36	85	175 " 240
16	28	42	75	210 " 295
18	32	42	75	270 " 370
20	36	48	65	340 " 460
22	40	48	65	415 " 575
24	43	48	65	500 " 700
26	47	60	60	665 " 920
28	51	60	60	750 " 1,050
30	54	60	60	860 " 1,200

Twin Engines.—Any of the foregoing horizontal engines may be coupled to another in order to obtain an increase of power, but it is open to question whether, if this be done, the moderate extra expenditure for a compound engine of equal power should not be incurred. A very good twin engine which really possesses a special merit, that of compactness, is made by many agricultural manufacturers, and runs in about the following proportions. It is a very customary and safe rule to assume the power of twin engines as two-thirds of the power of two single engines, but they will exceed this amount, as the following table will show.

TWIN-CYLINDER HORIZONTAL ENGINES.

Two Cylinders each	Revolutions per Minute.	Indicated Horse-Power at 80 Lbs. Pressure.		Cost.	Space Occupied.
		Economical Working Load.	Maximum Load.		
6 × 10	150	12	18	£115 = $575	10′ 0″ × 4′ 6″
6¾ × 12	135	16	24	£135 = $675	11 0 × 5 6
7½ × 12	135	20	30	£152 = $760	11 9 × 5 10
8¼ × 12	135	24	36	£175 = $875	12 6 × 5 11
8¾ × 14	125	28	42	£180 = $900	12 10 × 6 4
9½ × 14	125	32	48	£197 = $985	13 6 × 6 4
10½ × 14	125	40	60	£235 = $1,175	14 5 × 7 0
11½ × 16	112	50	75	£283 = $1,415	15 4 × 7 1
12½ × 18	100	60	90	£335 = $1,675	16 4 × 7 3
14 × 22	82	80	120	£440 = $2,200	18 6 × 9 2
16 × 24	75	100	150	£540 = $2,700	20 0 × 9 6

Probably the largest use of twin engines is in the portable and semi-portable form, where convenience of transport of a large power is desired, and where in many cases one cylinder can be disconnected temporarily when not required. Such engines correspond in size to the above, and save any cost of chimney, also requiring very little foundation, as they have the weight of the boiler and water to assist their steadiness.

For contractor's work, temporary installations, farm duties,

and such rough, hard work, these twin engines, especially when combined with the locomotive type of boiler, are to be recommended.

Compound Engines, Double and Triple.—All the previous considerations on the question of the economy of compounding engines apply with equal force to the horizontal type, whether fixed or portable.

The compound process has shown its superiority over the single cylinder, even apart from the adoption of condensation.

The horizontal form of engine is especially well suited to double-compounding, either by arranging the cylinders "tandem," one behind the other on a piston-rod common to both, or by making a double engine of it. It is by no means so well adapted for triple-compound work, and the vertical type is to be preferred for that purpose; although some very fine horizontal triples have been designed, they are costly compared to the marine pattern.

Good horizontal compound engines may be relied upon, with a good boiler, to work with a consumption of less than 2 lbs. of Welsh or anthracite coal per indicated horse-power per hour, when developing nearly their full power.

The compound engine may, in effect, be advantageously adopted wherever the load is reasonably constant, or the power of the engine is well above the demands made upon it. For irregular working, demanding much stopping and starting, it is better to adopt a single engine, and in the case of much sudden reversing, a twin engine.

Forms of Compound Engines.—Two well-known arrangements of double-compound cylinders in a horizontal form are in general use. They are the "coupled" and the "tandem." Each have merits for particular positions. Thus the latter is very narrow and long in proportion, and its work is all done on one crank. It is in high favour in north country factories, and is sometimes known as the Lancashire pattern.

The "coupled" is suited to bayonet and other patterns, and most large high-class engines are made of this form. It has two cranks, and when made condensing the air-pump is laid out on a foundation behind the low-pressure cylinder. For flour-mill work it is very suitable, and indeed for all general purposes where space for it can be found.

HIGH-SPEED COUPLED COMPOUNDS, SUITED FOR DIRECT DRIVING OF DYNAMOS AND CENTRIFUGALS.

Cylinders. Bore and Stroke in Inches.	Cost.
4½ and 7¾ × 5	£135 = $675
5¼ " 9 × 6	£150 = $750
6 " 10½ × 8	£180 = $900
7½ " 13 × 9	£220 = $1,100
8½ " 14¾ × 10	£260 = $1,300

A special class of these compound engines has been developed by the English agricultural engineers, which is arranged in a wrought-iron framework, and is in all respects similar to the engines supplied by them in the semi-portable form. These may be described as—

MODERATE SPEED COUPLED COMPOUND ENGINES, SUITED FOR LONG RUNS, WITH COMPACT AND CLOSE FRAMINGS OF "SEMI-PORTABLE TYPE."

CYLINDERS.			Revolutions per Minute.	Cost.
High-Pressure.	Low-Pressure.	Stroke.		
Inches.	Inches.	Inches.		
5½	9	12	180	£173 = $865
6½	10½	14	155	£193 = $965
7	11¼	14	155	£213 = $1,065
8	12¾	14	155	£253 = $1,265
9	14	16	135	£290 = $1,450
10	16	18	120	£351 = $1,755
11	17½	18	120	£406 = $2,030
11½	18	18	120	£497 = $2,485
13	21	24	90	£593 = $2,965
14	22½	24	90	£714 = $3,570

The speeds of above engines may be safely increased.

Large High-Class Coupled Compounds.—Where engines are to develop hundreds of indicated horse-powers, the conditions demand close calculation in each case; therefore, the lists prepared are not carried beyond the limit of 250 horse-power. And, without question, condensation should be brought into consideration and, if possible, adopted.

In dealing with the "Corliss" engine in the preceding chapter, information was given as to the usual sizes in arranging that type of engine as a compound. While large power engines of such high-class demand very careful estimates of cost to suit each case, the following costs of the smaller sizes will be a relative guide.

Tandem Compound Engines are commonly known in England as "Lancashire" engines, and are very widely adopted there for mill work. Although strung out, by the nature of their design, to a great length, they occupy very little width in proportion, and may thus be found specially suitable for mills where space is an object.

Arrangements should be provided whereby the piston of the high-pressure cylinder can be withdrawn without removing the low-pressure cylinder from its seat. Such engines are built in average sizes, as follows:

Cylinders. Bore.	Cylinders. Stroke.	Revolutions per Minute.	Indicated Horse-Power at 80 Lbs. Pressure.	Cost of Engine.	Cost of Condenser.
Inches.					
6½ & 12	× 14	125	24	£141 = $705	£28
7 & 12½	× 14	125	30	£157 = $785	£30
8 & 14	× 16	115	38	£173 = $865	£32
8½ & 15	× 16	115	44	£195 = $975	£34
9 & 16	× 18	110	55	£215 = $1,075	£38
10 & 18	× 21	85	65	£254 = $1,270	£44
12 & 21	× 24	80	85	£317 = $1,585	£51
13 & 22	× 24	80	100	£380 = $1,900	£66
14 & 24	× 24	80	110	£426 = $2,130	£70
15 & 26	× 30	70	140	£503 = $2,515	£80
16 & 28	× 36	60	180	£625 = $3,125	£100
17 & 30	× 39	55	220	£750 = $3,750	£152

In ordinary practice with these machines, the condenser is of the jet type, and the air-pump is arranged in line with the cylinders, and is operated by an extension of the piston-rod at the rear end. Better results are obtainable by the arrangement of the air-pump at a lower level, insuring complete drainage of the low-pressure cylinder.

Coupled Compound Engines of Bayonet Pattern, with Ordinary Slide-Valves and Automatic Control by Governor.

Cylinders.		Stroke. in Inches.	Revolutions per Minute.	Indicated Horse-Power at 80 lbs. Pressure.	Cost.
High-Pressure.	Low-Pressure.				
Inches.	Inches.				
8	14	16	115	40	£200 = $1,000
9	16	21	100	60	£245 = $1,225
10	18	21	90	75	£300 = $1,500
12	21	24	85	90	£375 = $1,875
13	22	24	85	105	£450 = $2,250
14	24	26	85	120	£500 = $2,500
15	26	30	75	160	£600 = $3,000
16	28	33	70	200	£740 = $3,700
17	30	36	65	240	£885 = $4,425

The above tables afford a choice of all types of horizontal engines, and the motives of selection may again be recited as consisting of—

Class of work to be done.

Economy of working, largely connected with available water-supply.

First cost.

Space occupied.

The respective merits of various makes of engines cannot here be entered into. Suffice it to say that solidity of design and excellence of construction should be sought, and wherever possible automatic expansion-gear should be adopted.

An immense amount of literature has been devoted to

the subject of the steam-engine, in which may be found more detailed records of performances and merits than it is possible here to give. A very comprehensive work, in which the whole subject is brought well up to date, is the work of Mr. D. K. Clark, on Steam, also Bourne's "Steam, Air, and Gas Engines."

CHAPTER XXIII.

THE PORTABLE STEAM-ENGINE.

ALTHOUGH in reality the portable, semi-portable (or semi-fixed) engine is nothing more than an ordinary horizontal, yet in its combination with the locomotive type of boiler, it has developed so striking a personality that it is entitled to recognition as a separate class.

The portable engine has been brought to such a pitch of perfection of manufacture that it frequently represents the best investment in a steam plant.

Added to this is the extreme convenience of compactness and portability, and now that the compounding and jacketing of cylinders has been accomplished at commercial prices, its economy is unequalled, unless by specially high-class and well-arranged engines and boilers.

The "underneath," "semi-portable," or "semi-fixed" engine, which is best described by the former title, is frequently the preferable form, and, generally speaking, the types may be considered as adapted best to the following purposes :

Use a Portable, Single, or Double Cylinder for :	Adopt an Underneath Pattern, Single or Compound for :
Temporary installations of power. Agricultural machinery generally. Driving portable flour mills. Rough grinding and crushing by disintegrators. Driving centrifugal pumps. Brick-making machinery. Circular saws. Cotton gins. General contractors' work. General builders' work.	Saw and planing mills. Workshop driving. Electric driving. Export where fuels are dear. Driving small flour-mills up to 3 pairs of 4-feet stones.

Proportions of Ordinary Portable and Semi-Portable Engines.

(For Dimensions of Boilers, see Chapter XXV.)

So-called "Nominal" Power.	Effective H.-P.		Cylinders.		Ordinary Revolutions per Min.	Boiler Pressure.	Size of Internal Fire-Box.			Number of Tubes.	Heating Surface.	Cost of Complete Engine and Boiler.	
	Economical.	Maximum.	Bore in Inches.	Stroke in Inches.			Long.	Wide.	High.			Portable.	Semi-Portable.
Single Cylinder.						Lbs.					Sq. Ft.		
2½	3	7	5	8	188	80	15″	20″	25″	15 of 2½″	56	£100= $500	£96= $480
3	4	9	6	9	165	80	15½	20	25½	15 of 2½	73	£130= $650	£125= $625
4	6	12	6½	10	150	80	20½	23½	29½	18 of 2½	90	£150= $750	£140= $700
5	7	15	7½	10	150	80	20½	27½	32½	19 of 2¾	105	£165= $825	£155= $775
6	9	18	8½	12	135	80	24	27½	32½	19 of 2¾	108	£180= $900	£170= $850
7	10	21	8¾	12	135	80	24	30¼	36	24 of 2½	124	£195= $975	£180= $900
8	12	24	9½	12	135	80	27	30¼	36	27 of 2¾	154	£210=$1,050	£195= $975
9	13½	27	10	12	135	80	27½	32	36	30 of 2¾	173	£225=$1,125	£210=$1,050
10	15	30	10½	14	125	80	27½	33½	39	32 of 2¾	192	£240=$1,200	£225=$1,125
12	18	36	11½	16	112	80	31	33½	39	33 of 2¾	208	£280=$1,400	£260=$1,300
Twin Cylinders.													
8	12	24	6¼ & 6¼	10	150	80	27	30¼	36	27 of 2¾	154	£235=$1,175	£220=$1,100
9	13½	27	7 & 7	10	150	80	27½	32	36	30 of 2¾	173	£250=$1,250	£235=$1,175
10	15	30	7½ & 7½	10	150	80	27½	33½	39	32 of 2¾	192	£265=$1,325	£250=$1,250
12	18	36	8 & 8	12	135	80	31	33½	39	33 of 2¾	208	£305=$1,525	£285=$1,425
14	20	40	8¾ & 8¾	12	135	80	33	36	41	36 of 2¾	228	£340=$1,700	£320=$1,600
16	24	48	9½ & 9½	12	135	80	35½	39	43	40 of 2¾	240	£375=$1,875	£355=$1,775
20	30	60	10½ & 10½	14	125	80	37½	39	45	45 of 2¾	303	£450=$2,250	£425=$2,125
25	38	75	11½ & 11½	16	112	80	39	42	48	50 of 2¾	340	£540=$2,700	£510=$2,550
30	45	90	12½ & 12½	16	112	80	43½	44	50	52 of 2¾	380	£640=$3,200	£610=$3,050
40	80	120	14 & 14	18	100	80	44	47	54	60 of 2¾	460	£740=$3,700	£710=$3,550
50	100	150	16 & 16	18	100	80	52	55	55	70 of 2¾	600	£840=$4,200	£810=$4,050

The general practice of manufacturers has been, and continues to be, to denominate these excellent engines by the misleading term of nominal or rated powers, and to give no indication of their dimensions nor of the relative heating surface of the boilers accompanying them. Above will be be found figures relating to these points, information on which should be insisted upon previous to purchasing.

The effective powers given above may be relied upon in regular work, and the maximum may be exceeded for occasional duties.

Compound Portable and underneath engines are now made by all the leading manufacturers, and have given excellent results, largely due to the close union between engine and boiler, reducing losses by radiation, leakage, and waste spaces. In the "Underneath" form the engine is arranged much as in a locomotive, the cylinders deriving the benefit of some heat from their proximity to the smokebox, and great stability from the superincumbent weight of the boiler.

The proportions of cylinders adopted by different makers vary very much, but the following are about average sizes :

So-called "Nominal" Power.	Cylinders.		Stroke in Inches.	Boiler Pressure.	Cost.	
	High-Pressure.	Low-Pressure.			Portable.	"Underneath," or Semi-Portable.
	Inches.	Inches.				
8	5½	9	10	120 lbs.	£300=$1,500	£310=$1,550
10	6½	10½	10	"	£340=$1,700	£340=$1,700
12	7	11	12	"	£380=$1,900	£380=$1,900
16	7¾	12	12	"	£450=$2,250	£450=$2,225
20	9	14	14	"	£550=$2,750	£530=$2,550
25	10	16	16	"	....	£650=$3,250
30	11	17½	16	"	....	£760=$3,800
35	11½	18	16	"	....	£950=$4,750
40	12¾	20	18	"	....	£1,050=$5,250
50	14	22	18	"	....	£1,250=$6,250

These compound engines are very economical when put to regular work, but as has been before remarked, where the duty lays much below their normal power, they are inadvisable, as the work of the steam when cut off at too early a point is not distributed evenly in the cylinders. Such an error has been frequently committed by electrical engineers, whose anxiety to reach a high economy while providing a large reserve of power has led them into a very opposite result.

SECTION V.

CHAPTER XXIV.

STEAM-BOILERS.

IT cannot be too clearly understood that the economy of a steam-engine is wrapped up in that of the boiler which supplies it with steam, and in or under which is burned the fuel that is the true source of the power of the apparatus.

Hence, too much care can hardly be employed both in the selection of a boiler and in its proper location and attendance.

The forms of the steam-boiler are almost more numerous than those of the steam-engine, and an immensity of discussion has raged round their respective merits. Broadly speaking, they are all to be classified under two heads, viz., those

Internally fired and those Externally fired.

Where large furnace area is required the latter form has the advantage ; and great advances have been made by the tubulous boilers, which are now even disputing with the "Scotch" boiler the work of supplying steam at sea.

Practically speaking, the grate area may, in these apparatuses, be made of any required dimensions, while as regards the use of high-pressures, they offer exceptional advantages.

The Power of Boilers.—On this subject we are at once confronted with that senseless jack-in-the-box, the nominal horse, but in an aggravated form. For, whereas in the case of an engine a relation may be established between it and the actual force of an effective horse-power, in the case of a boiler we have to get at its value filtered through that of

the engine which the boiler is to supply. And, inasmuch as the steam raised in a boiler may be economically or wastefully employed, it follows that the identical boiler with a poor engine may be ratable at an entirely different horse-power to what it would be when working in conjunction with a better motor.

As a case in point, assume a Lancashire boiler, 20 feet long × 6 feet 6 inches diameter, which will be found to be rated in commercial lists as 25 nominal horse-power.

Such a boiler is capable, with ordinarily good coal, of evaporating, that is, turning into steam, some 3,000 lbs. weight of water per hour, at a pressure of 100 lbs. per square inch.

This steam, made use of in various engines, will give results as follows:

I. A high-speed single-cylinder non-condensing engine, at the rate of 40 lbs. of steam per horse-power per hour $= \frac{3,000}{40} = 75$ horse-power.

This would be given by a cylinder $14\frac{1}{2}'' \times 20''$ stroke at 100 lbs. pressure, which is equivalent to 18 nominal horse-power.

II. A long-stroke single-cylinder engine, non-condensing, using, say, 35 lbs. of steam per horse-power per hour $= \frac{3,000}{35} = 84\frac{1}{2}$ horse-power.

This would be afforded by a cylinder of less diameter, say $12'' \times 26''$ stroke, which, at 100 lbs. pressure, would be rated at 15 nominal horse-power.

III. The latter-class engine, in conjunction with a good condenser, would make more economical use of the same steam, requiring, say, only 30 lbs. of steam per horse-power per hour $= \frac{3,000}{30} = 100$ horse-power,

which would be provided under these circumstances by a cylinder 11″ × 26″, rated only at 13 nominal horse-power.

IV. The crowning absurdity is reached by the rating of a compound engine using the same steam, at the rate of 22 lbs. per horse-power per hour $= \frac{3,000}{22} = 136$ horse-power, for which an engine 13″ and 26″ × 24″ might be adopted, which would be rated at no less than 40 nominal horse-power!

This example will demonstrate not only how futile and absurd a term that of "a nominal horse-power" has become, but will show the essential point of relation between boiler and engine, and the only proper parallel of power, which is—

BOILER.	ENGINE.
Production of pounds-weight of steam.	Consumption of pounds-weight of steam.

This comparison is simple if the quality of the engine be known, and as the performances of these machines are well established facts lying within certain limits, there is no difficulty about comparing the power of boiler with that of the engine, and deciding upon the proportions of the one to suit the other. The first point is—

THE CONSUMPTION OF WATER TURNED INTO STEAM BY VARIOUS ENGINES PER HOUR.

Type.	Per Indicated Horse-Power.	Per Effective Horse-Power.
Non-condensing—Small, high speed	40 lbs.	46 lbs.
" Moderate speed	35 "	40.25 lbs.
" Long-stroke, well made.	28 "	32.25 "
Condensing—Moderate speed	25 "	28.75 "
" Long-stroke, well-made	24 "	27.5 "
Compound—Non-condensing	22 "	25.33 "
" Condensing	18 to 20 lbs.	20.75 to 23 lbs.
Triple compound—Condensing	15 to 18 "	17.25 to 20.75 "

A rough rule is to divide the figure 200 by the square root of the pressure employed, thus :

$$\frac{200}{\sqrt{\text{Pressure}}} = \left\{ \begin{array}{l} \text{lbs. of steam or water per} \\ \quad \text{horse-power per hour.} \end{array} \right.$$

This, however, ignores all the surrounding circumstances detailed in above table.

Now, knowing the water consumption, we only require every boiler to be indicated by its capacity in pounds of water turned into steam per hour. This, however, is what not one maker in one hundred will do, or perhaps, in some cases, be able to do. Some will say it depends on the fuel, the chimney, the draft, the stoking, etc., but these are mere excuses for ignorance, and the information should be insisted upon.

The calculation is a very simple one : We require so many square feet of effectively placed heating surface to heat the pounds of water which the engine will use up. We also require so many square feet of properly arranged grate area to enable us to burn the fuel necessary for that heating of the water.

These proportions vary in different types of boilers, the effectiveness of the heat being made use of in a better or an inferior manner, as the case may be. This is due to the design and disposition of the plates above and below the flame, while length of the plate or tube surface to be travelled by the flame has also a considerably reducing value on its heating effect after a certain distance traversed.

Lancashire boilers, under ordinary conditions of draught and firing, will burn economically about 15 lbs. of good coal per square foot of grate per hour, and as 1 lb. of coal of this character is equal to an evaporation of 8 lbs. of water, we get a performance of $8 \times 15 = 120$ lbs. of water for each square foot of grate surface.

This must be, of course, combined with a proper amount of heating surface, and practice shows that in the above class of boiler 120 lbs. of water (nearly 2 cubic feet) is evaporated for 24 to 28 square feet of heating surface.

Reducing and combining these results, we get, for each pound of water per hour required by the engine,

.008 of a square foot of grate,
.234 of a square foot of heating surface.

Cornish boilers work approximately under the same conditions, and therefore should be similarly proportioned.

The vertical type of boiler has done as good work as 8 lbs. of water per pound of fuel on trial, and 60 lbs. of water evaporated from 16 square feet of heating surface when specially designed and cared for. But the ordinary commercial boiler should be reckoned at a rate shown by practice to be about 6 lbs. of water per pound of fuel burnt, and 12 lbs. burnt per square foot of grate per hour.

Therefore, for each pound of water to be evaporated per hour, allow

.014 of a square foot of grate area,
.33 of a square foot of heating surface.

The locomotive type of boiler used for stationary purposes is very economical, and will evaporate under ordinary draught about 120 lbs. of water with 18 square feet of heating surface, and with forced draught has done as good as 120 lbs. with only 12 square feet. Such, however, are not the ordinary conditions we have to deal with, and the regular performance should be based on the evaporation of 120 lbs. of water from a heating surface of 16 to 18 square feet; the latter, being the safer, we assume as a basis.

Therefore, for each pound of water to be evaporated per hour, allow

.0071 of a square foot of grate area,
.15 of a square foot of heating surface.

Externally fired boilers of the closed-shell type, commonly but erroneously known as multitubular, evaporate about 120 lbs. of water from 32 square feet of heating surface, and may be arranged to burn fuel as well as a Lancashire boiler per foot of grate surface. As, however, there is no difficulty in their case in having almost as large a fire-grate built as may be desired, it may be assumed in the following proportion :

Grate area not less than .008 sq. ft., but larger if convenient.
Heating surface, .266 per lb. of water evaporated.

Tubulous boilers, such as Belleville, Babcock's, Root's, etc., are excellent steam-raisers, and have frequently given results exceeding all other types. Thus as high as over 10 lbs. of water for a lb. of fuel has been reached, and a corresponding consumption of fuel per square foot of grate of 10 to 15 lbs. Averaging this at 12 lbs. as a moderate figure, we get 120 lbs. of water per square foot of grate, or .008 sq. ft. per lb.

The proportion of heating surface provided by these boilers is large, and, what is more to the point, it is effectively placed for advantageous catching of the heat.

Therefore for every lb. of water required allow—

Not less than a grate area of..... .008 sq. ft.
and a heating surface of .25 sq. ft.

Marine type or "Scotch" boilers.—These have, at sea, done most excellent work, but it must be remembered that they work under very specially favorable conditions for high efficiency. Thus they run for many days on end, they work in combination with a very perfect system of condensation and of draught, so that the low figure at which

they turn out a horse-power must not be relied upon under land conditions. It will be seen how much higher the grate area is in proportion to the heating surface than land boilers.

They are customarily taken at:

$$\left.\begin{array}{ll}\text{Grate area,} & .006\\ \text{Heating surface,} & .222\end{array}\right\}\ \text{Sq. ft. per lb. of water to be evaporated.}$$

Summarizing the above facts, we arrive at the proper way in which to decide upon the proportions of a boiler of a given type, as follows:

$$\text{Indicated horse-power} \times \overset{\text{Lbs. of Water.}}{\left\{\begin{array}{c}40\\ \text{or}\\ 35\\ \text{or}\\ 28\\ \text{or}\\ 25\\ \text{or}\\ 24\\ \text{or}\\ 20\\ \text{or}\\ 18\\ \text{or}\\ 15\end{array}\ \text{According to type of engine.}\right\}} \times \overset{\text{Square Feet of Heating Surface.}}{\left\{\begin{array}{c}.234\\ \text{or}\\ .33\\ \text{or}\\ .15\\ \text{or}\\ .266\\ \text{or}\\ .25\\ \text{or}\\ .222\end{array}\ \text{According to type of boiler.}\right\}} = \left\{\text{Heating surface of boiler required.}\right.$$

And, similarly,

$$\text{Indicated horse-power} \times \left\{\begin{array}{c}40\\ \text{or}\\ 35\\ \text{or}\\ 28\\ \text{or}\\ 25\\ \text{or}\\ 24\\ \text{or}\\ 20\\ \text{or}\\ 18\\ \text{or}\\ 15\end{array}\ \text{According to type of engine.}\right\} \times \left\{\begin{array}{c}.008\\ \text{or}\\ .014\\ \text{or}\\ .0071\\ \text{or}\\ .006\end{array}\ \text{According to type of boiler.}\right\} = \left\{\text{Grate area necessary.}\right.$$

Affording simply so many figures of consumption against so many figures of production, which I have reduced to tabular form as follows, covering all types of engines and boilers, and requiring only to be multiplied by the number of indicated horse-powers requisite.

SQUARE FEET OF HEATING AND GRATE AREAS TO BE ALLOWED FOR ONE INDICATED HORSE-POWER IN ALL TYPES OF BOILERS AND FOR ALL CLASSES OF ENGINES.

Class of Engine.	Steam or Water turned into Steam, Used to Produce 1 Ind. H.-P.	Types of Boilers. Lancashire or Cornish.		Vertical Cross Tube or Multitubular.		Locomotive or Portable.		Externally Fired Shells called "Multitubular."		Tubulous Boilers.		Marine Type or "Scotch" Pattern.	
		Heating. (.234 per lb.)	Grate. (.008 per lb.)	Heating. (.33 per lb.)	Grate. (.014 per lb.)	Heating. (.15 per lb.)	Grate. (.007 per lb.)	Heating. (.266 per lb.)	Grate. (.008 per lb.)	Heating. (.25 per lb.)	Grate. (.008 per lb.)	Heating. (.222 per lb.)	Grate. (.006 per lb.)
Non-condensing small high speed	40	9.36	.32	13.2	.56	6	.28	10.64	.32	10	.32	8.88	.24
Non-condensing moderate speed.	35	8.19	.28	11.55	.49	5.25	.245	9.31	.28	8.75	.28	7.77	.21
Non-condensing well-designed, long stroke.....	28	6.55	.224	9.24	.392	4.2	.196	7.448	.224	7	.224	6.216	.168
Condensing, moderate speed, single cylinder..	25	5.85	.2	8.25	.35	3.75	.175	6.65	.2	6.25	.2	5.55	.15
Condensing, well-made high-class single cylinder..	24	5.61	.192	7.92	.336	3.6	.168	6.384	.192	6	.192	5.328	.144
Compound, non-condensing.....	22	5.148	.176	7.26	.308	3.3	.154	5.852	.176	5.5	.176	4.884	.132
Compound, condensing........	20	4.68	.16	unsuitable		3	.14	5.32	.16	5	.16	4.44	.12
Large high-class compound condensing	18	4.21	.144	unsuitable		2.7	.126	4.788	.144	4.5	.144	3.996	.108
Triple compound condensing.....	15	3.51	.12	unsuitable		2.25	.105	3.99	.12	3.75	.12	3.33	.9

The object of the present work being to provide the means of ascertaining powers and proportions for practical work, and not the rules for actual construction, the following formulæ relating to the proportions of boilers will be found sufficient for the purpose :

The relative value of heating surfaces :

Horizontal surfaces above the flame, 1.00.
Vertical surface above the flame, .50.
Horizontal surface below the flame should not be taken into consideration.
Tubes and flues, 1.25 times their diameter.
Convex surfaces above the flame, $1\frac{1}{8}$ of their diameter.

Relative steam and water space :

In portable or locomotive type boilers, .26 of a cubic foot of water per square foot of heating surface.
In Lancashire and Cornish boilers, .82 of same.
In Scotch or marine, .33 to .49.

The ratio of water space to steam space is :

In locomotive boiler,	2.00	water to	1	of steam.
Lancashire and Cornish,	1.08	"	1	"
In the Scotch,	1.33	"	1	"

Flat surfaces, as in locomotive type fire-boxes, should be stayed at the following distances, and, inversely, the safe steam pressure to be carried by a new fire-box with stays at certain distances apart may be ascertained from them.

DISTANCE APART OF STAYS IN FLAT SURFACES.

Pressure in Lbs. per Square Inch.	¼" plate.	⅜" plate.	½" plate.	⅝" plate.
	Inches.	Inches.	Inches.	Inches.
60	4.08	6.12	8.16	10.20
80	3.53	5.29	7.07	8.83
100	3.16	4.74	6.32	7.90
120	2.88	4.34	5.77	7.22
140	2.67	4.00	5.34	6.68
160	2.50	3.74	5.00	6.24

Testing Boilers.—The usual method of proving boilers before use is to subject them to a hydraulic pressure of

double the working figure. This rough and ready rule appears to most uninformed people to afford a full margin of safety. It has, however, been pointed out frequently that this excessive strain is not unlikely to develop the very evil it is sought to indicate by its means, and by straining unduly some part of the boiler to cause a secret fracture which will afterwards be the seat of serious trouble. This may especially be the case under high working pressures. Equal security is afforded by a less proof strain which, while exceeding the working pressure by a sufficient margin, does not impose an undue amount on stayed portions. When all is said and done as regards these hydraulic proofs, they go but a small distance in comparison with real care in design, calculation, and especially in manufacture. The tendency of modern practice being to render boilers more machine-made articles than hand-made is all in the direction of security, and there is no better assurance of the strength and life of a boiler than the reputation and equipment of its manufacturers.

An essential feature should be made of the *drilling* of all holes in plates, and riveting by hydraulic machinery.

General Essentials for Good Boiler Work.—Steel plates to have a tenacity of not less than 26 tons per square inch, and not more than 30 tons per square inch, with an elongation of not less than 20 per cent. in a test piece of 10 inches long.

Riveting.—All rivet holes to be drilled, those in shells to be drilled after the shell is bent and bolted in position. All rivets closed by hydraulic machinery.

Rivet seams.—In the direction of length of shell or barrel to be double riveted. Ring seams may be single riveted.

For pressures exceeding 100 lbs. per square inch it is a better practice to use cover plates, or strips with 4 lines of rivets. These cover plates should be planed down to an edge where they meet ring seams.

Furnace and flue tubes to be rolled up truly cylindrical and welded. The weld arranged so as *not* to come under the direct action of the flame.

Tubes for tubular boilers to be lap-welded of Best Best iron or of drawn steel.

End plates, as far as possible, made in one piece, and machine-flanged for attachment to shells.

Edges of plates should be planed.

Man-holes and mud-holes to be strengthened by an internal ring riveted round the opening.

Cast-iron for seatings, flanges, or attachments should not be used.

CHAPTER XXV.

TYPES AND COSTS OF BOILERS.

The "Locomotive" or "Portable" Form.—Having concluded consideration of the steam-engine by the tabulation of the portable form, which is combined with the locomotive type of boiler, it will be convenient to proceed first to the details of this form of steam-raiser, which ranks high for economy and compactness.

The design of the locomotive-boiler has grown out of the requirements of propulsion on railroads, and its perfection is certainly due largely to the practical knowledge gained thereby. Its form is that due to a square furnace surrounded on all parts but the bottom by a similarly shaped casing, the intermediate space being filled with water to a given level. Out of one side of the outer casing projects the barrel, closed at the farther end by what is known as the back tube-plate. From this plate to the furnace extend a number of tubes, through which the flame from the fire finds vent into the smoke-box, or case, which forms a continuation of the barrel. By this means the fire may be said to be entirely inclosed in water.

It would be beyond the purpose of this work to enter into details of the discussions which have raged round the proportions of these boilers, the means to be adopted for the prevention of burning tubes and tube-plates, and the respective merits of steel and of copper for the fire-boxes.

Suffice to say that the "portable" boiler, as made by the majority of English and American boiler-makers, is an excellent apparatus, both as regards proportions and material.

That these proportions vary very much with different makers goes without saying, also that many boilers are sent

out for work above their capacity, and some in which modifications of their proportions to suit particular fuels and waters would be better made.

It is a general practice to provide a standard size of fire-box suited to good coal-burning therein, and to charge an extra sum per "nominal" horse-power for any enlargement of this. The proportions of such enlargement, too, are usually concealed in England under some adjective, such as the "Colonial," "Wood-burning," or "Continental" fire-box. What possible technical value can attach to such absurd terms no one has ever been able to say, nor to show why a "Continental" fire-box should accord with a certain power on the Continent and be unsuitable for the same in Kamschatka! The sooner such mercantile excrescences are decently buried along with the nominal and rated horses the better for the reputation of the engineering profession.

Nothing whatever in the way of terms should be allowed to conceal the heating and grate surface of these or of any other boilers.

Heating surface of these boilers is easily and cheaply increased by many merchants by the simple method of adding somewhat to the length of the barrel, and thus correspondingly extending the length of the tubes. Manufacturers charge very little in proportion for such an addition, and thus a 12-horse-power boiler of a value of £130, or $650, is, by the extra expenditure of a few pounds, made to pass for one of 14- or 16-horse-power, with a cost to the purchaser probably of 20 per cent. more. This is aggravated sometimes by the fact that many makers err in having the tubes in their standard sizes of boilers too long.

My own experiments have shown that any tube surface exceeding 80 per cent. of the entire heating surface is superfluous. A common practice is to make the proportion 90 per cent., but the tabulated sizes which follow run nearer the former figure.

Proportions of Locomotive Type, or Portable, Boilers.

Heating Surface in Sq. Ft.	Grate Area in Sq. Ft.	Cylinders of Portable Engines.		So-called Nominal Horse-power.	Total Dimensions.		Fire-box.				Barrel.		Plates for 70 Lbs. Pressure.				Tubes.		Wheels		Costs.			
							Internal.		Casing.												For 70 Lbs. Pressure.		For 100 Lbs. Pressure.	
		Bore.	Stroke.		Length, including the Smoke-box.	Height.	Long.	Wide.	Long.	Wide.	Diameter.	Length.	General.	Fire-box.	Front Tube Plate.	Back Tube Plate.	Number.	Diameter.	Front.	Rear.	£	$	£	$
90	3.04	6¾''	10''	4¾	7' 8''	3' 8''	1' 5''	2' 2''	2' 0''	2' 8''	2' 3''	4' 7''	1/4	5/16	7/16	7/16	18	2¼''	3' 0''	4' 1''	66=	330	90=	450
105	3.28	7½ / 8	10 / 12	5 or 6	9 0	3 9	1 5	2 4	2 0	2 10	2 3	5 8	1/4	5/16	7/16	7/16	19	2¼	3 1	4 3½	83=	415	100=	500
120	3.66	8¼	12	7	9 3	3 11	1 6	2 6½	2 1	3 0	2 7	5 9	5/16	5/16	7/16	7/16	24	2½	3 1	4 3½	92=	460	105=	525
150	5.16	9½	12	8	10 0	4 1½	2 0	2 7	2 6½	3 3½	2 7¾	6 1	5/16	3/8	7/16	1/2	27	2¼	3 3¼	4 5½	100=	500	125=	625
170	5.84	10	12	9	10 6	4 4	2 2	2 8½	2 9	3 5	2 9	6 3	5/16	3/8	1/2	1/2	32	2½	3 3½	4 5½	110=	550	140=	700
190	6.07	10½	14	10	10 9	4 7	2 2½	2 9	2 9	3 5	2 10	6 7	5/16	3/8	1/2	1/2	32	2¼	3 3¼	4 5½	120=	600	152=	760
210	6.99	11½	16	12	11 2	4 9	2 4	3 0	2 11	3 8	3 1	6 10	5/16	3/8	1/2	9/16	33	2¼	3 6½	4 8½	130=	650	165=	825
		Double																						
230	7.8	8¼	12	14	11 6	5 1	2 5	3 3	3 1	3 10	3 4	7 1	3/8	3/8	9/16	9/16	40	2¼	3 6½	4 8½	150=	750	175=	875
260	8.9	9½	12	16	11 8½	5 3	2 9	3 3	3 6	3 10	3 5	7 4	3/8	3/8	9/16	5/8	46	2¼	3 9½	4 11	160=	800	190=	950
290	10.34	10	14	18	12 6	5 7	2 11½	3 6	3 7	4 1	3 8	7 7	3/8	3/8	9/16	5/8	50	2¼	3 9½	4 11	170=	850	210=	1,050
310	11.9	10½	14	20	13 6	6 1	3 3	3 8	4 1	4 4	3 10	8 1	7/16	3/8	9/16	5/8	52	2¼	3 9½	4 11	200=	1,000	245=	1,225
360	14.17	11½ / 12	16	23	14 10	6 7	3 7½	3 11	4 4	4 7	4 0½	8 7	7/16	3/8	9/16	5/8	60	2¼	3 9½	4 11	245=	1,225	320=	1,600

The following is another set of sizes which may be usefully compared with the above, having enlarged fire-boxes for burning wood or inferior fuels.

56	2.7	5½	8	2½	7 6½	3 9	1 6	1 10½	2 0½	2 4½	2 4½	4 3	1/4	5/16	3/8	3/8	16	2½	2 6	3 6	65=325	....
73	3 02	6	9	3	8 0	3 9	1 8½	1 10½	2 3	2 4½	2 4½	4 6	1/4	5/16	3/8	3/8	17	2½	2 6	3 6	66=330	....
90	4.35	6¾	10	4	8 11½	3 10	2 0½	1 11⅝	2 7	2 6	2 6	5 0	5/16	5/16	7/16	7/16	22	2½	2 10	4 0	70=350	96=480
105	4.62	7½	10	5	9 1	4 4	2 0 7/16	2 3½	2 7	2 10	2 10	5 0	5/16	5/16	7/16	7/16	30	2¼	2 10	4 0	88=440	108=540
108	5.46	8½	12	6	9 11¼	4 4	2 4 9/16	2 3½	2 11¼	2 10	2 10	5 6	5/16	5/16	7/16	7/16	33	2¼	2 10	4 0	93=465	111=555
124	6	8¾	12	7	10 2¼	4 9	2 4½	2 6¼	2 11¼	3 0¾	3 0¾	5 9	5/16	5/16	1/2	1/2	35	2¼	3 6	4 6	103=515	116=580
154	7.1	9½	12	8	11 3	4 10	2 10¼	2 6¼	3 5	3 0¾	3 0¾	6 4	5/16	3/8	1/2	1/2	35	2¼	3 6	4 6	112=560	137=685
192	8.37	10½	14	10	12 0	5 1	3 0¼	2 9½	3 7	3 4	3 4	6 9	3/8	3/8	9/16	9/16	40	2¼	3 10	4 10	135=675	167=835
208	9.07	11½	16	12	12 9	5 2	3 3¼	2 9½	3 10	3 4	3 4	7 3	3/8	3/8	9/16	9/16	44	2¼	3 10	4 10	148=740	183=915

CHAPTER XXVI.

LANCASHIRE AND CORNISH BOILERS.

THE Lancashire boiler has attained, perhaps, the highest position as a steam raiser for land purposes, and has done so by reason of its undoubted merits of simplicity and accessibility. Its construction is so well known that it is unnecessary to devote space to a description longer than to say that it consists of a shell, or tube, closed at both ends, and pierced from end to end by two fire-flues or tubes, as against one in the Cornish boiler. In these fire-tubes the furnaces are situated, and the flame is led by brick flues along the sides and under the bottom of the boiler to the chimney. The boiler is usually made from 6 feet to 7 feet diameter, and any excess of power required over that dimension it is usual to supply by additional boilers, where, placed in batteries of two or more, they can be readily stoked and managed by a very little increase in labour. For all permanent plants, where the power exceeds 100 horse-power, and economy both in fuel and in labour are looked for, the choice must lay between the Lancashire and a tubulous boiler.

In the Lancashire form is included the excellent improvements effected by the well-known Manchester firm, whose type of furnace, and their cross and tapered tubes, have given a title to the boiler they make.

The calculation of the internal tubes of Lancashire and Cornish boilers is a matter requiring care, and is the subject of a number of rules. It is the part of the boiler most liable to cause accident from its being subject to compres-

sive strain, which, when the plates become overheated when short of water, may buckle the plate and cause collapse of the tube.

The safe working pressure for iron tubes as well as for steel may be found by the following rule :

$t =$ thickness of the plate in inches.
$L =$ the length of the bare tube between strengthening rings or flanges.
$D =$ the diameter of the tube in inches.

$$\text{Safe pressure for iron} = \frac{t^2 \times 90{,}000}{D \times L + 1}, \text{ or for steel} = \frac{t^2 \times 99{,}000}{D \times L + 1}.$$

And the proper thickness of plate is to be found thus, pressure being known or assumed :

$$t = \frac{\text{Working pressure} \times D}{8{,}000}, \text{ or for steel} = \frac{W. P. \times D}{8{,}800}.$$

The effect of cross tubes in the strength of flues is not greatly to increase their strength, though in case of a collapse of the tube, they may mitigate its serious effects. They should not, therefore, be taken into account in calculating the strength of a flue. From an economic point of view they do good work, greatly increasing the circulation from the dead water below the tube to the heated surfaces above, and are strongly to be advised. Their cost is always an addition to the boiler, averaging £3, or \$15, each, riveted in place.

Lancashire boilers are now made up to 8 feet diameter, for working pressures of 100, 120, 140, and even 160 lbs. per square inch. For certain positions they may be beneficial, but should not be decided upon until the merits of "water-tube" or tubulous boilers have been studied.

For high-class electric installations, where pressures have

a tendency to be fixed at the higher figures mentioned, the latter type has of late secured the preference.

The following are good sizes of Lancashire boilers, well proportioned as to diameter and length, and may be accepted as an average for a pressure of 80 lbs. per square inch :

LANCASHIRE BOILERS.

Diameter.	Length.	Flues.	Galloway Cross Tubes in Flues.	Cost, Including the Cross Tubes.
Ft. In.	Ft. In.	Ft. In.		
6 2	19 0	2 4	4	£245 = $1,225
6 6	22 0	2 6	6	£325 = $1,625
6 8	24 3	2 6	6	£365 = $1,825
6 8	27 0	2 6	6	£400 = $2,000
7 0	28 0	2 8	6	£455 = $2,275

The only difference in the Cornish boiler is that it has one flue instead of two, as in the Lancashire form.

Cornish boilers are made from 3 feet diameter to 6 feet, after which dimension two flues become advisable. Their proportions are of infinite variety between these sizes and lengths from 7 feet to 30.

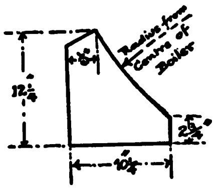
The following are sizes selected as average to afford comparison of costs :

CORNISH BOILERS FOR 70 LBS. WORKING PRESSURE.

Diameter.	Length.	Flue Diameter.	Cost, Complete with Fittings.
Ft. In.	Ft. In.	Inches.	
3 3	7 6	19	£45 = $225
4 0	10 0	24	£64 = $320
4 9	15 0	30	£98 = $490
5 0	18 0	30	£122 = $610
FOR 80 LBS. WORKING PRESSURE.			
5 6	20 0	33	£163 = $815
6 0	22 0	36	£214 = $1,070

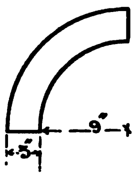
Setting Boilers.—In Lancashire and Cornish boilers the cost of the "setting" forms a large proportion of their expense.

They should be sustained in position on special shaped fire-bricks, which are supplied by all the leading firms dealing in such material.



Width, 11⅞″ each.

The side flues are nearly arched over by special fire-bricks of a half-arch shape.



Width, 11⅞″ each.

For a boiler	28	feet long	provide of each	of above,	60
"	27	"	"	"	58
"	24	"	"	"	52
"	22	"	"	"	48
"	19	"	"	"	42

In addition, provide for setting a 28-feet boiler the following materials:

Quick lime..........................	29 bushels.
Sand..............................	144 "
Fire-clay	36 "
Ordinary bricks	four thousand.
Red bricks for surface work........	nine thousand.

Inclination and Levels.—The boilers should be set in the "setting" at an inclination of ½ inch in 10 feet toward the blow-off cock.

The dead plate should be set 2 feet — 8 inches above floor of stoke-hole.

The best position for the fire-level inside flues is about 20 inches to 22 inches from the interior top of a flue.

Fire-bars should be inclined 1 in 10 to 1 in 12 away from the stoking-door. Length of dead-plate, 10 inches. Thickness of fire-bars, ½ inch to ¾ inch. Spaces between them, ⅜ inch to ½ inch. Fire-doors about 16 inches × 13 inches.

Water level should be set for a minimum of 4 inches above flue top, and an average of 9 inches.

Gauge glasses should be 10 inches long.

Oval man-holes are usually 18 inches × 15 inches.

Vertical Boilers.—This term is applied to boilers in which the shell stands vertically, and covers indiscriminately a large variety of internal design. The leading types are the cross-tube and multitubular. The former has the usual circular internal fire-box, across which are fitted as many large water-tubes as can be conveniently arranged. These greatly add to the efficiency of the boiler, and are better when made of a taper form or set at a slight angle from one side to the other, thus allowing the steam particles or bubbles to have a natural ascent.

This form of boiler is very simple and substantial, and easier to clean than most other types. Like all ordinary vertical boilers, its weak point is the passage of the up-take through the steam space, rendering it liable to burn out in time.

To overcome this objection quite a number of patented and non-patented arrangements of parts have been devised. Some of these are meritorious. All should be looked into to see that they afford no corners for the reception of de-

posit, and that all parts are accessible to cleaning and repair.

The same remarks apply to the numerous forms of multitubular vertical boilers, some of which contain, in proportion to their sizes, an immense heating surface. Of these the boilers of fire-engines are examples, the fire-boxes of which are crossed by a multitude of small brass water-tubes, effecting very quick steam-raising.

The well-known "Field" drop-tubes have found favour, but rapidly burn out when used with water in which much deposit occurs.

For small powers, up to 15 horse-power, the vertical boiler is very suitable, and its convenience for placing and absence of brickwork render it very simple of adaptation. Wherever possible it should be clothed well with one of the many non-conducting materials.

VERTICAL MULTITUBULAR BOILERS.

Heating Surface.	Grate Area.	Shell.				Fire-box.				Tubes.		Cost.
		Height.		Diameter.		Height.		Diam.		No.	Diam.	
Sq. Ft.	Sq. Ft.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.			
36.75	2.18	6	3	2	0	4	3	1	5½	7	2¾	£28 = $140
43.5	2.76	6	3	2	3	4	3	1	9	10	2¾	£33 = $165
71	3.54	7	0	2	6	4	6	1	11½	7 & 7	2¾ 1¾	£38 = $190
95.7	4.9	7	6	3	0	5	0	2	4½	1 & 10	2¾ 1¾	£51 = $255
119	6.3	8	3	3	4	5	3	2	8	12 & 12	2¾ 1¾	£65 = $325
144	7.87	8	6	3	9	5	4	3	1	30	3½	£75 = $375
206	9.16	8	6	4	0	5	8	3	3	42	3½	£82 = $410
238	10.08	8	9	4	3	5	11	3	4	45	3½	£98 = $490
274	11.5	8	9	4	6	5	10	3	8	54	3½	£108 = $540

Some improved vertical boilers are made with an up-take brought over to one side, from which horizontal fire-tubes extend to a smoke-box situated at one side. In these all

the heated surfaces are under water, and a large addition is made to the life of such a boiler by this means.

A sample list of such boilers will serve to afford a comparison of cost and proportions.

SPECIAL VERTICAL MULTITUBULAR BOILERS.

Heating Surface.	Height.		Diameter.		Cost.
Sq. Ft.	Ft.	In.	Ft.	In.	
80	8	0	3	0	£77 = $385
105	8	6	3	3	£95 = $475
140	9	0	3	6	£116 = $580
180	10	0	4	0	£137 = $685
225	10	6	4	3	£158 = $790
280	11	0	4	6	£180 = $900
310	11	6	4	9	£207 = $1,035
400	12	0	5	0	£234 = $1,170
460	13	0	5	6	£266 = $1,330
610	14	0	6	0	£308 = $1,540
730	14	6	6	6	£360 = $1,800
790	15	0	7	0	£412 = $2,060
970	16	0	7	6	£464 = $2,320
1,100	16	6	8	0	£536 = $2,680

No form of boiler has received more attention at the hand of inventors and improvers than the vertical, and very many types are now offered on the market. The particular points to be sought in a selection are, accessibility of the tubes and interior, unrestricted steam space, and a minimum of heated plate surface exposed to steam and not to a covering of water.

CHAPTER XXVII.

HORIZONTAL MULTITUBULAR BOILERS.

THESE boilers are, in their simplest form, shells pierced from end to end by a quantity of tubes. The boiler is then set in a brickwork "setting," and one great advantage the arrangement possesses is that the fire-grate area, which is below the body of the boiler, may be of any reasonable size. Thus the form of boiler becomes suited to the burning of poorer fuels in an economical manner. It may also be set in a flue leading from a furnace, and in this manner make effective use of waste gases. For general conditions, and with good fuel, its use is superseded by the water-tube or tubulous boilers, which exceed it in efficiency though not in simplicity.

English practice is to use a shell of a length not exceeding double the diameter, such as the following:

HORIZONTAL MULTITUBULAR BOILERS FOR 75 LBS. WORKING PRESSURE.

Diameter.	Length.	Number of Tubes 3″ Diameter.	Cost Complete, with Fittings and Furnace and Smoke-box Fronts and Doors of Cast Iron.
Ft. In.	Ft. In.		
3 6	6 6	20	£54 = $270
3 9	8 0	22	£65 = $325
4 0	9 9	26	£88 = $440
4 6	10 0	34	£115 = $575
5 0	11 0	40	£144 = $720
6 0	12 0	44	£180 = $900

In the United States, where these boilers are in extended use, their proportions are of endless variety, and they are

often made with tubes of large size, suited to the burning of poor fuels and sawdust. The following are about average sizes, and particulars of the furnace and smoke-box arrangements. It will be seen that they are longer in proportion to their diameter than in English practice.

Horizontal Multitubular Boilers. American Proportions. For 75 Lbs. Working Pressure.

Square Feet of Heating Surface.	Diameter of Boiler.	Thickness of Shell.	Thickness of Heads.	Length of Tubes.	Number of Tubes (3 in. diameter).	Cost.	Weight of Boiler. Lbs.	Weight of Boiler Fixtures.
	Inch.	Inch.	Inch.	Feet.			About	
152	32	$\frac{1}{4}$	$\frac{3}{8}$	7	20	$304	1,600	2,600
185	34	$\frac{1}{4}$	$\frac{3}{8}$	7	25	$314	2,000	2,700
221	36	$\frac{1}{4}$	$\frac{3}{8}$	8	28	$342	2,300	2,800
290	36	$\frac{1}{4}$	$\frac{3}{8}$	10	28	$379	2,700	3,100
306	42	$\frac{9}{32}$	$\frac{3}{8}$	8	38	$426	3,100	3,700
380	42	$\frac{9}{32}$	$\frac{3}{8}$	10	38	$475	3,700	4,000
447	44	$\frac{9}{32}$	$\frac{3}{8}$	10	46	$505	4,100	4,100
534	44	$\frac{9}{32}$	$\frac{3}{8}$	12	46	$554	4,800	4,300
621	44	$\frac{9}{32}$	$\frac{3}{8}$	14	46	$614	5,400	4,600
600	48	$\frac{5}{16}$	$\frac{7}{16}$	12	52	$648	5,600	4,800
698	48	$\frac{5}{16}$	$\frac{7}{16}$	14	52	$712	6,400	5,100
730	54	$\frac{5}{16}$	$\frac{7}{16}$	12	64	$764	6,800	5,300
906	54	$\frac{5}{16}$	$\frac{7}{16}$	15	64	$864	8,100	5,600
915	60	$\frac{11}{32}$	$\frac{7}{16}$	12	82	$893	8,400	5,900
1,064	60	$\frac{11}{32}$	$\frac{7}{16}$	14	82	$980	9,400	6,300
1,213	60	$\frac{11}{32}$	$\frac{7}{16}$	16	82	$1,069	10,500	6,600
1,350	66	$\frac{3}{8}$	$\frac{7}{16}$	15	98	$1,213	12,200	7,200
1,455	66	$\frac{3}{8}$	$\frac{7}{16}$	16	98	$1,258	12,900	7,400
1,735	72	$\frac{7}{16}$	$\frac{1}{2}$	16	120	$1,479	15,800	8,400

The smoke-box is of heavy sheet iron, with a heavy cast-iron front-plate with double folding doors swinging horizontally, and a cast-iron angle-plate extending around the smoke-box, and made to fit against the face of the brick-work, the bottom of it resting on the furnace front and supporting the smoke-box.

The furnace front is made of cast iron, the main web or plate, with the furnace and ash-pit doors, being set back about seven inches from the face of the brickwork, and

fitting around the bottom of the boiler, with two fire- and two ash-pit doors. The fire-doors are arched, and are provided with cast-iron liners bolted to the doors. The furnace part of the front should be arranged for lining with fire-brick, and have cast-iron arches over the fire-doors to prevent brick from falling down if loosened, and be also provided with flanges for securely binding into the arch, and a cast-iron angle-plate bolted on to support the grates.

The smoke-boxes for boilers less than 44 inches in diameter have usually one door, and the furnace fronts have one fire- and one ash-pit door.

The boiler fixtures usually comprise the smoke-box and furnace front, as described above, grates, grate bearers, rear arch bars, door and frames for rear ash-pit, safety valve, steam gauge, water gauge fitted to stand pipe, gauge cocks (3) with pipes, whistle and pipe, blow-off valve, check valve, stop valve, smoke-stack and guy rods, and all arch-binder bolts, with nuts and outside plates necessary for properly securing furnace front and smoke-box in position in the arch and binding arch together.

Grates for boilers having 7-feet and 8-feet tubes, are 36 inches long; with 10-feet tubes, 44 inches; with 12-feet tubes, 48 inches; and with 14, 15, and 16-feet tubes, 54 inches long, and the width of the grates in all cases equals the diameter of the boiler.

Smoke-stacks for these boilers are generally made of iron, up to 28 inches diameter, of No. 16, and larger sizes of No. 14 iron.

CHAPTER XXVIII.

THE TUBULOUS BOILER.

This form of steam-raiser has come rapidly to the front of recent years, its construction being now much superior to what it was when it first attracted attention. The use of cast-iron connections between the tubes has been discarded for wrought iron, or steel forged into shape under hydraulic pressure.

Its convenience for transportation is great; it may be made in pieces small enough for carrying on mule-back.

Repairs are easily effected by comparatively unskilled labour, if spare parts are provided, while immunity from accident is the strong feature of the system. Tubes are employed to carry the water under heat, which are capable of resisting many times the working pressure, and thus for all high pressure the tubulous boiler is the safest to be employed.

Some of them are now made in a rather clumsy yet useful portable form, a list of which are appended, and the introduction of their use into marine practice has already begun. A disadvantage under certain conditions is the cumbrous proportion of the brickwork and great height of the apparatus, but the following table of a well-known type of these boilers gives information enabling a comparison to be drawn with other boilers as to space, weight, and other features. The cost of such boilers varies considerably with locality, but they may be averaged at about £30 or $150 per ton weight.

TUBULOUS STEAM-BOILERS.—*D. K. Clark.*

Heating Surface.	Ratio of Heating Surface to Grate Surface.	Grate Area.	Furnace. Long.	Furnace. Wide.	Horse-powers of 30 Lbs. of Water at 70 Lbs. Pressure.	Total Space Occupied. Long.	Total Space Occupied. Wide.	Total Space Occupied. High.	Tubes. Number of Sections.	Tubes. Tubes in each Section.	Tubes. Length of Tubes.	Total Weight of Iron-work.
Sq. Ft.		Sq. Ft.	Inches.	Inches.		Ft. In.	Ft. In.	Ft. In.			Feet.	Lbs.
118	22.6 to 1	5.21	30	25	10	9 3	4 5	7 7	3	4	6	6,700
181	24.8	7.29	42	25	15	11 3	4 5	8 1	3	5	8	8,200
287	18.6	15.35	42	32	25	13 3	5 0	8 7	4	5	10	11,000
402	33.1	12.02	54	32	35	15 3	5 0	9 1	4	6	12	13,600
512	32.0	16.00	72	32	45	19 0	5 8	12 3	4	7	14	16,500
585	36.5	16.00	72	32	51	19 0	5 8	12 9	4	8	14	17,000
840	36.5	23.00	72	46	73	21 0	6 10	13 3	6	7	16	22,000
1,193	44.4	26.83	84	46	104	23 0	6 10	13 9	6	9	18	28,000
1,378	44.6	30.91	84	53	120	23 0	7 5	13 9	7	9	18	30,000
2,111	41.1	51.33	84	88	184	21 0	10 4	13 3	12	9	16	46,000
2,756	46.3	59.50	84	102	240	23 0	11 6	14 0	14	9	18	55,000
			Two furnaces, each,									
1,025	32.0	32.00	72	32	90	19 0	9 10	12 3	8	7	14	30,000
1,171	36.5	32.00	72	32	102	19 0	9 10	12 9	8	8	14	32,000
1,411	36.0	39.00	72	39	122	19 0	11 0	12 9	10	8	14	35,000
2,111	39.3	53.66	84	46	184	21 0	12 2	13 3	12	9	16	45,000
2,756	44.6	61.82	84	53	240	23 0	13 4	14 0	14	9	18	57,000
5,513	46.3	119.00	84	102	480	23 0	22 0	14 0	28	9	18	108,000

The length of fire-grate in English practice is somewhat less than above.

At a close comparative test in 1876 between one of these boilers and a Lancashire, the following were comparative results :

	Tubulous.	Lancashire.
Heating surface in square feet	1,680.	973.
Grate area in square feet	45.5	39.
Steam space in cubic feet	138.	168.56
Water space in cubic feet	235.	587.24
Indicated horse-power at 30 lbs. of water per horse-power, 70 lbs. pressure	155.5	115.2
Coal burned per hour per square foot of grate area	9.77	8.87
Water evaporated per lb. of coal	12.13	11.55

By which it will be seen how closely these excellent forms of steam-raisers approach each other in economy, the advantage gained by the tubulous form being due to its superior quantity and disposition of heating and grate surface.

In a portable form the tubulous boiler may be obtained as follows :

Heating Surface in Square Feet.	Grate Area in Square Feet.	Weight in Pounds, of Dry Steam per Hour.	Dimensions of Apparatus.					
			Height.		Width.		Depth.	
			Ft.	In.	Ft.	In.	Ft.	In.
50	1.6	220	7	5	2	10	2	7
70	2.5	330	7	5	3	2	2	11
95	3.7	490	7	5	3	6	3	3
120	4.4	550	8	1	3	6	3	7
120	5.1	660	7	5	3	10	3	7
150	6.8	820	7	5	4	2	3	11
160	6.1	710	8	1	3	11	3	11
200	8	930	8	1	4	4	4	3
250	10.3	1,200	8	1	4	8	4	7
300	12.9	1,450	8	1	5	1	4	11
360	15.6	1,750	8	1	5	6	5	3

The following proportions of tubulous boilers are those of the "Belleville," a type which finds much favour on the European continent. They are based on the use of a pressure of 170 lbs. per square inch, or, say, 150 to 160 lbs. working pressure at the engine, and are thus very suitable for use with triple-compound engines.

Heating Surface in Square Feet.	Grate Area in Square Feet.	Weight in Pounds, of Dry Steam per Hour.	Space Required.					
			Height.		Width.		Depth.	
			Ft.	In.	Ft.	In.	Ft.	In.
290	9	1,000	10	6	4	11	6	9
380	12	1,350	10	6	5	7	6	9
470	15	1,700	10	6	6	4	6	9
520	17	2,000	12	3	6	10	7	11
560	18	2,050	10	6	7	0	6	9
640	21.25	2,500	12	3	7	9	7	11
650	21	2,400	10	6	7	9	6	9
740	24	2,750	10	6	8	5	6	9
760	25.5	3,000	12	3	8	7	7	11
790	26	3,200	13	9	9	3	9	4
830	27	3,100	10	6	9	2	6	9
880	29.75	3,500	12	3	9	5	7	11
920	30	3,450	10	6	9	10	6	9
980	32	3,950	13	9	9	6	9	4
1,000	34	4,000	12	3	10	3	7	11
1,010	33	3,800	10	6	10	7	6	9
1,100	36	4,150	10	6	11	4	6	9
1,120	38.25	4,500	12	3	11	2	7	11
1,170	39	4,700	13	9	10	6	9	4
1,240	42.50	5,000	12	3	12	2	7	11
1,360	46	5,450	13	9	11	7	9	4
1,550	53	6,200	13	9	12	7	9	4
1,740	60	6,950	13	9	13	8	9	4
1,930	67	7,700	13	9	14	9	9	4

CHAPTER XXIX.

CHIMNEYS.

It is not too much to say that many good boilers are spoiled by their bad chimneys, and while there is considerable latitude permissible in the dimensions of the latter in order to obtain given results, many chimneys are overtaxed and the blame then laid on the boiler.

The cost of a chimney has naturally to be taken into account in deciding on a steam installation, and its size is quite as important a factor as proper proportions in the boiler itself. This part of an installation having very often to depend upon the knowledge or efforts of the purchaser, is frequently left to the decision of a local builder, and therefore I proceed to give the precise rules for their proportions.

If the steam is not to be condensed, and may be utilized to create an artificial draught, as in locomotive or portable engines, a very small amount of chimney is required, sufficient only to carry off the vapours from the neighbourhood.

The minimum length of chimney should be 4 times the diameter. Any increase in draught to be obtained from lengthening the chimney is very slow.

The exhausting or blowing power of the blast-pipe in short chimneys, such as those of locomotive boilers, is found by the following rule of Mr. Longridge's :

$d =$ diameter of exhaust or blast-pipe in inches, which may be slightly contracted or tapered from the full exhaust pipe area to obtain a more forcible jet.

$D =$ diameter of the chimney in inches.

$p =$ the pressure of the exhaust in lbs. per sq. in.

The exhaust pressure or draught in inches of water will be $\left\{ \dfrac{37 \times d \times 1.662 \times p \times 0.8}{D \times D} \right.$.

For small powers, an ordinary house chimney will often be found to be sufficient. In such cases the bends or turns of the iron tube to connect the top of the boiler flue to that of the chimney should be made as straight as possible, and not less at any part than the area of the boiler flue.

Where the flue has to be carried horizontally any distance it is necessary to allow more chimney area.

Roughly speaking, flues should be built about one-eighth of the area of the fire-grate, but not at any part of less area than the top of the chimney. In building flues avoid all sharp turns and corners, and especially all contractions and alterations of shape, and if unavoidable, lead one part into the other by gradual tapered surfaces.

Smoke, like air and like water, loses velocity by hindrances such as projections in passages. Of course it is not possible to avoid offsets, as bricks cannot be carved to a smooth shape for all internal bends, but the latter may be arranged to be so gradual that the set-offs are small.

The first consideration will be the area and height of the necessary chimney, and then will come the question of the material of which it may be constructed.

Under the increasing stringency of municipal regulations as to the emission of smoke from factory stacks, it is important that the height of town chimneys should be liberally in excess of the necessities of the case. At the same time a good deal may be done in smoke destruction by some of the devices for mechanical feeding of the fuel, which admits of exact regulation of the air-supply.

The height of chimneys varies, of course, very considerably with local circumstances, but the ordinary necessities of draught, and also of sanitary considerations, are met by the following heights in general practice.

Height of Chimneys.—

Coal Consumed per Hour.	Height.
Up to 100 lbs.	60 feet.
" 500 "	100 "
" 1,000 "	120 "
" 2,000 "	140 "
" 3,000 "	160 "
" 4,000 "	180 "
" 5,000 "	200 "
To carry off the gaseous products in towns without any possibility of nuisance	250 "

These heights are frequently varied by local considerations, bye-laws, freaks of surveyors, fears of neighbours, etc.

The height being ascertained, the following settle the area :

Where the rate of fuel consumption is less than 21 lbs. per square foot of grate per hour—

$$\frac{.07 \times \text{lbs. of fuel consumed}}{\sqrt{\text{Height above grate, in feet}}} = \left\{ \begin{array}{l} \text{The area at top or smallest} \\ \text{part in square feet.} \end{array} \right.$$

Where only the area of the fire-grate is known—

$$\frac{1.25 \times \text{grate area}}{\sqrt{\text{Height above grate, in feet}}} = \text{area in square feet;}$$

or,

$$\frac{180 \times \text{grate area}}{\sqrt{\text{Height in feet}}} = \text{area in square inches.}$$

Where the fuel used is known—

$$\frac{15 \times \text{lbs. of fuel per hour}}{\sqrt{\text{Height in feet}}} = \text{area in square inches.}$$

Where the indicated horse-power is known—

$$\frac{100 \times \text{H.-P. of engine}}{\sqrt{\text{Height in feet}}} = \text{area in square inches.}$$

The height and areas being thus settled, we have to deal with any addition to one or other rendered necessary by the length of horizontal flue. Up to 50 feet addition of horizontal flue the areas obtained above will prove sufficient, but above that length some addition should be made to the area of the chimney in the following proportion :

A = Area in square feet as found above.
B = Area allowing for horizontal flues.

Where the length of flues in feet is	100 to 200	200 to 400	400 to 600	600 to 800	800 to 1,000	1,000 to 1,500	1,500 to 2,000
B will equal...........	$A+\frac{A}{.853}$	$A+\frac{A}{.708}$	$A+\frac{A}{.625}$	$A+\frac{A}{.561}$	$A+\frac{A}{.514}$	$A+\frac{A}{.433}$	$A+\frac{A}{.382}$

Draught.—The velocity of the draught is found thus :

H = height of chimney in feet,
T = temperature of gases entering base of chimney,
t = temperature of gases at top of chimney ;

then,

$$36.5 \times \sqrt{4\,(T - t)} = \text{Velocity in feet per second.}$$

To find the draught of a given chimney, in inches of water, proceed as follows :

The draught =

$$\left(\frac{7.6}{\text{Temperature of the external air above zero.}} - \frac{7.9}{\text{Temperature of the gases in the chimney above zero.}}\right) \times \left\{\begin{array}{c}\text{Height of}\\ \text{chimney}\\ \text{in feet.}\end{array}\right.$$

If the draught to be obtained be known, and the height to produce it be needed, then

$$\text{The height} = \frac{\text{The draught in inches of water}}{\left(\frac{7.6}{\text{Temperature of external air above zero.}} - \frac{7.9}{\text{Temperature of gases above zero.}}\right)}$$

The following table, giving both height and area for given powers, may be found useful for ready reference :

SIZES OF CHIMNEYS SUITED FOR VARIOUS POWERS.—*Babcock.*

Diameter of Chimney in Inches.	Height of Chimneys in Feet.											Effective Area of Chimney in Sq. Ft.	Actual Area in Square Feet.
	50	60	70	80	90	100	110	125	150	175	200		
	Horse-Powers Equal to 30 Lbs. Steam per Horse-Power per Hour at 70 Lbs. Pressure.												
18	23	25	27									.97	1.77
21	35	38	41									1.47	2.41
24	49	54	58	62								2.08	3.14
27	65	72	78	83								2.78	3.98
30	84	92	100	107	113							3.58	4.91
33		115	125	133	141							4.47	5.94
36		141	152	163	173	182						5.47	7.07
39			183	196	208	219						6.57	8.30
42			216	231	245	258	271					7.76	9.62
48				311	330	348	365	389				10.44	12.57
54				363	427	449	472	503	551			13.51	15.00
60				505	539	565	593	632	692	748		16.98	19.64
66					658	694	728	776	849	918	981	20.83	23.76
72					792	835	876	934	1,023	1,105	1,181	25.08	28.27
78						995	1,038	1,107	1,212	1,310	1,400	29.73	33.18
84						1,163	1,214	1,294	1,418	1,531	1,637	34.76	38.48
90						1,344	1,415	1,496	1,639	1,770	1,893	40.19	44.18
96						1,537	1,616	1,720	1,876	2,027	2,167	46.01	50.27

The above has been calculated on the assumption that while the effective area of a chimney varies inversely as the square root of the height, the actual area should be greater to allow for the retardation of velocity by the walls. The basis is then taken that this is equal to a layer of air of 2 inches thick over the whole interior surface, and the effective area is calculated as follows :

$$\text{Effective area} = \frac{\begin{array}{c}0.3 \times \text{number of horse-powers of 30 lbs. of steam}\\ \text{per hour at 70 lbs. pressure}\end{array}}{\text{The square root of the height}}.$$

Brick Chimneys.—The standard English practice for brick chimneys is given by the following rules :

The external diameter of a brick chimney at the base should be one-tenth of the height unless supported by some

other structure. The batter, or taper, may be from $\frac{1}{16}$ inch to $\frac{1}{4}$ inch per foot on each side. A good proportion for thickness is to commence at the top with one brick thick, say 9 inches, increasing $\frac{1}{2}$ a brick, say $4\frac{1}{2}$ inches, for each 25 feet downwards. But under 3 feet in diameter a chimney might be safely made to $\frac{1}{2}$ a brick thick for the upper 10 feet. Over 5 feet diameter the thickness may be well increased to $1\frac{1}{2}$ bricks at top.

The proportions of a chimney require to be decided so as to afford it sufficient stability to withstand the force of the highest winds. This has been brought to the shape of a formula, in which its safe weight can be decided on assumed figures of height and breadth of base.

The safe weight equals the following:

$$\frac{\text{The average breadth} \times \text{the height squared}}{\text{the breadth of base}} \times \left\{ \begin{array}{l} \text{a coefficient of wind} \\ \text{pressure per square} \\ \text{foot of area.} \end{array} \right.$$

This latter item varies with the form of the chimney, being,

For a square chimney,		56.
For an octagon	"	35.
For a round	"	28.

Brickwork weighs about 100 to 130 lbs. per cubic foot, hence the safe amount of brickwork can readily be calculated.

Foundation.—This should be carefully levelled and proved to be sound, from 1 to 3 feet thick of concrete being laid as a base for the brickwork foundation, of a size proportioned to the strength or weakness of the natural foundation.

Brickwork Base.—The brickwork base to be tapered in 6-inch courses to the exterior of the chimney-shaft, the exterior at the base being, for a chimney 50 yards high, approximately double the interior diameter of the shaft.

Batter of Shaft.—The batter of the shaft should be about

1 inch to a yard, or 1 in 36, a little more or a little less, according to the size of the chimney and other circumstances.

Thickness and Finish at Top.—Unless the chimney is a very small one, the thickness at the top should not be less than 9 inches, and should be finished off with a cap of fireclay blocks, secured by dowels, or with a cast-iron cap.

Cavity and Lining.—The bottom part should be made with a cavity, to reduce weight and economise material and labour. The cavity is formed by building the interior of chimney at the base of greater diameter than the finished size, and then building a lining to the chimney of 4½-inch firebricks, stiffened by six radial walls of 4½-inch brick work jointed into the outside casing. Holes are commonly built through the outside casing to allow for the expansion of the enclosed air.

Interior of Chimney.—In modern practice the inside of the chimney is not a smooth tube, but formed by a series of set-offs, so as to avoid cutting the bricks. The wall is formed of full courses of 4½ inches, and, being set out back from the minimum size of the chimney, continually approaches that size until the batter, or taper, brings the brickwork to the minimum interior size, when a set-off is again made, and the thickness of the brickwork reduced by 4½ inches. This, with a batter of 1 in 36, takes place every 13 feet 6 inches.

Firebrick Lining.—This need not, except in short chimneys, extend to more than one-half of the height, but the rest of the chimney should be lined with sound hard bricks.

Section.—The chimney may be square, octagon, or circular in shape, the latter being much better in every respect, except for small chimneys, the bricks being made to the circular form.

In the United States a number of stacks have been successfully built in the form of two concentric shells, forming

two thin chimneys, the form of the outer shell being varied from a plain circle so as to give it great strength against wind pressure though built very thin. A star shape, or square with the corners recessed, is one such form. The interior shell, being entirely protected by the outer, is a mere ring of single bricks.

Iron Chimneys.—Many of these are made for export, of strong plates, with or without a cast-iron base-plate and guy ropes. They are well adapted for situations where it is not convenient to build a brick shaft, and are sent out in lengths nested one within the other to save freight, and can be readily put together at destination.

The efficiency of iron stacks is somewhat greater than brick chimneys, as there is no infiltration of air, as through brickwork. They require to be kept painted, which is a standing addition to cost, and where not bolted down to a strong foundation they need to be braced by guys or stays to surrounding objects. Such stays should be attached about two-thirds of the height up, and should have an area equal to $\frac{1}{1000}$th of the exposed area of the stack. With such stays the usual rules as to the weight of a chimney necessary to afford sufficient stability may be much modified.

Consumption of Smoke.—The consumption of smoke in towns is a question of great importance, and in deciding upon the use of steam it should be carefully considered.

A great deal may be done, even with poor fuel, by the use of automatic stokers, which feed the material in a regular stream at the proper point for complete combustion. Proper proportions of furnace and disposition of the bridge will cause almost entire consumption of the smoke.

The steam-blast fitted to a furnace will aid in reducing smoke to a minimum.

At a pressure of 70 lbs. per square inch the outflow of steam through a pipe of 1 square inch area..........................	= 1 lb. per second,

Or,

The weight of steam through an orifice 1 inch square........... $\Big\}$ = $\frac{1}{70}$th of the pressure.

Many excellent apparatuses for self-feeding, smoke-reduction, and use of poor fuels without nuisance, are obtainable in the form of improved furnaces, fire-bars, steam-nozzles, hollow and other fire bridges, and doors.

SECTION VI.

CHAPTER XXX.

THE POWER OF THE EXPANSION OF GASES.

The Gas Engine.—The expansions of gases in the gas-engine have been found to be exactly controllable, inasmuch as the admixture of gas and air may be automatically regulated and further modified by the amount of compression under which they are fired.

Thus, coal-gas mixed with air in different proportions not only gives under explosion a variable maximum pressure, but occupies a different period of time in attaining it.

Explosions of Gas and Air.

1 volume of gas with 13 volumes of air reaches a maximum of 52 lbs. per square inch above the atmosphere in .28 of a second.

1 volume	to	11	volumes	of air	= 63	lbs. in	.18	of a second.
1	"	9	"	"	= 69	"	.13	" "
1	"	7	"	"	= 89	"	.07	" "
1	"	5	"	"	= 96	"	.05	" "

This maximum pressure is made use of in a cylinder just as in a steam-engine, and the time is adjusted to suit the speed of the engine. Loss of power results when it occurs too late in the stroke.

The maximum is usually arranged to be reached at about $\frac{1}{10}$th of the stroke, and should always be within this extent.

The mean effective pressure in most "Otto"-type engines

with English gas is between 50 and 60 lbs. per square inch.

Ignition.—A lead of the ignition-valve is set, of about $\frac{1}{16}$th, to ensure early explosion when the dead-centre is turned.

There are several forms of ignition apparatus; viz., electrical, by direct flame, or by a heated tube. The latter, though apt to be more sluggish in action, is the most reliable.

Compression.—The compression of the mixture previous to explosion will be to about 40 lbs. per square inch above the atmosphere.

The question of the amount of compression applied to the mixture of gas and air is an important one, as upon it depends largely the resultant pressure after explosion.

Thus, if the compression be doubled the maximum pressure is doubled.

For example, if the mixture of 1 of gas to 7 of air be compressed to 15 lbs. above the atmosphere, then the maximum pressure will be,

$$(89 + 15) \times 2 = \left\{ \begin{array}{l} \text{208 lbs. per square inch total, or 193 lbs.} \\ \text{per square inch above atmosphere.} \end{array} \right.$$

On the other hand, if the mixture be heated before explosion the resulting pressure will be less. Therefore all gas-engine cylinders are cooled with a copious supply of cold water passing round them, and which is usually arranged with a large tank and connecting pipes to circulate itself by gravity.

The essential features necessary for the adoption of a gas-engine motor are, therefore, gas and a moderate supply of water.

The latter may be a town supply, the quantity wasted not being large.

The former may be any town gas-supply. If of what is known as 16-candle power quality, the mean effective press-

ure in the cylinder will be about 55 to 60 lbs. per square inch on the piston, the maximum pressure possibly reaching from 140 lbs. to 180 lbs. per square inch.

The consumption of such gas will vary somewhat according to the size of engine, but will vary from 12½ cubic feet to 22 cubic feet per indicated horse-power per hour. The older types of gas-engines, which were non-compression, were very wasteful of gas, and little engines of that type used up to 90 cubic feet per horse-power per hour.

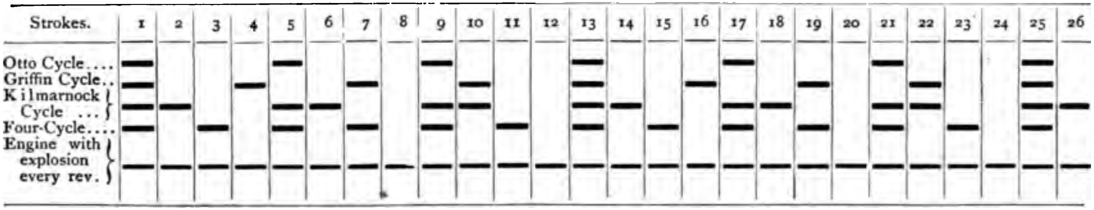
Cycles of Operation.—Modern practice now universally adopts compression, and the chief difference between gas-engines of different makes lays in what is known as their "cycle." This is the order in which they draw in gas and air, compress and explode them. Thus, in the well-known "Otto" the piston serves as pump and motor, and an impulse is given to it at full power by an explosion once in every two complete revolutions. These comparative cycles are illustrated by a simple diagram opposite, showing the action of their governing apparatus in varying or retarding explosions.

It will be obvious from a study of this diagram that there is a great difference in the regularity of rotation of gas-engines. The advantage would appear to be greatly in favour of those which employ an explosion every revolution when working at full power. Such engines are made, and, although subject to some practical difficulties, are sure to be improved in detail and may become the standard form of the future.

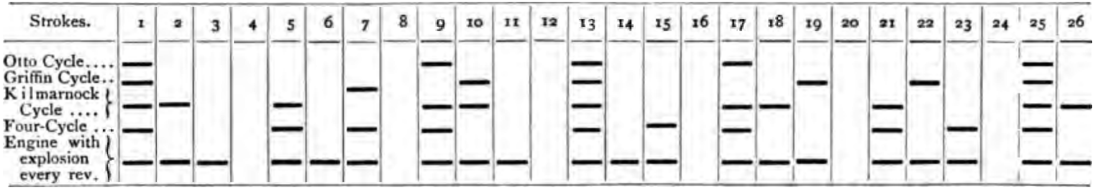
It is clear that as a gas-engine cannot be expected to be working always at exactly full power, the less distance between impulses the better. The difficulty is to some extent got over by the employment of two coupled engines, in which an alternation of explosions may be arranged.

Still it remains the fact that the weak point in the gas-engine, as compared with the steam-engine, is that varia-

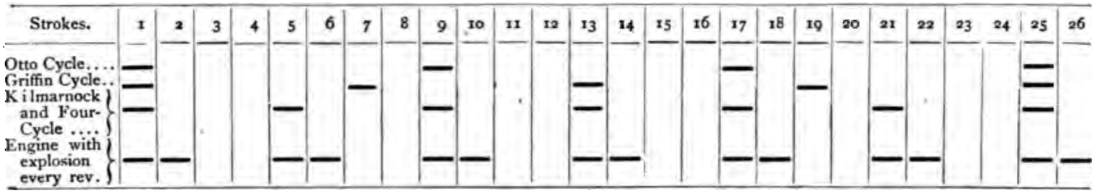
EXPLOSIONS IN GAS-ENGINES OF SEVERAL TYPES AT FULL POWER.—*Hartley.*



AT THREE-QUARTER POWER.



AT HALF-POWER.



tions in power in the former are obtained by missing impulses, not by grading the force of those impulses.

Therefore, where great regularity of rotation is an object gas-engines should not be employed, except by coupling two machines together. In electric driving very fair steadiness may be obtained by carefully arranging the proportions of the engine to its work, and a great number are at work on such duties both with and without accumulators.

The use of these overcomes nearly all difficulty as regards unsteadiness, although when charging them at the same time in which they are being used for lighting, the variations of the engine will be visible in the lights to a modified extent.

Attendance.—The essential economy effected by the use of the gas-engine over steam is the saving in attendance. Where this is coupled with a low price of town-gas, or the use of the Dowson apparatus, described in Chapter XV., a very sensible diminution in running cost is effected.

A gas-engine, when once started, requires very little attention for hours at a time, and is really entirely free from danger if the pipes and connections be maintained in proper order.

An undoubted disadvantage in many situations is the disagreeable smell given off by any leak, however small, and the harsh noise of the exhaust, only partly mitigated by the use of silencing-boxes and baffles.

Gas-engines are now being put into factories to replace steam under certain circumstances, where labour is dear and gas is cheap. They are being made in powers exceeding 100-horse power, and fitted with self-starting apparatus, overcoming the necessity of starting the engine by pulling it over the dead-centres by the spokes of the fly-wheel by hand.

Economy.—With various types of engines the Dowson fuel-gas apparatus has given most economical results, which

run from .86 to 1.2 lb. of fuel consumed for an indicated horse-power in an hour, or from 1 lb. to 1.94 lb. per brake horse-power per hour.

With town-gas, as previously stated, about 16 to 18 cubic feet per indicated horse-power per hour is a common result.

Comparatively with coal this may be taken roughly at from 2 to 2¼ lbs. per horse-power per hour.

Naturally the best results are reached when the engine is developing full power.

GENERAL PARTICULARS OF GAS-ENGINES.

Indicated H.-P.	Effective H.-P.	Revolutions.	Size of Belt Pulley.	Floor Space Occupied.	Weight of Engine. Net.	Weight of Engine. P'ck'd	Diameter of Gas Pipe.	Size of Meter.	Cost of Engine.	Cost of Water Tank.
			Inches.	Ft. In. Ft. In.	Cwt.	Cwt.	In.	Lights	£ $	£ s. $
2.7	1.5	200	10 × 5	4 0 × 2 9	8	10	½	5	48 = 240	1 10 = 7.50
4.	2.7	200	12 × 6	5 0 × 3 2	16	19	½	10	59 = 245	2 10 = 12.50
5.7	4.	200	12 × 6	5 6 × 3 6	23	25	¾	15	68 = 340	3 10 = 17.50
7.	5.	200	18 × 7	6 0 × 3 7	28	32	¾	15	78 = 390	3 10 = 17.50
9.5	7.	200	18 × 8	6 4 × 3 9	34	38	1	18	92 = 460	4 0 = 20
12.5	10.5	200	21 × 9	7 2 × 4 4	42	46	1	20	106 = 530	4 10 = 22.50
17.	12.	185	24 × 12	8 6 × 4 9	56	60	1¼	30	116 = 580	4 10 = 22.50
18.5	13.5	180	24 × 12	8 6 × 5 6	65	70	1½	40	125 = 625	5 0 = 25
20.5	15.	180	27 × 12	8 9 × 5 6	72	77	1½	50	133 = 665	6 0 = 30
23.	17.	180	30 × 12	9 0 × 5 10	78	83	2	50	139 = 695	6 10 = 32.50
25.	19.	180	30 × 12	9 6 × 6 2	85	93	2	60	144 = 720	7 0 = 35
27.	23.	180	36 × 12	10 0 × 7 0	95	106	2	80	160 = 800	10 0 = 50
30.5	24.5	170	42 × 14	10 6 × 7 6	102	115	2¼	80	177 = 885	16 0 = 80
56.	28.	170	48 × 14	11 0 × 7 6	110	122	2½	100	200 = 1,000	20 0 = 100
46.	36.	160	54 × 18	11 6 × 8 0	130	150	2½	150	236 = 1,180	25 0 = 125

The oil for lubricating a gas-engine should be carefully selected, but is not more in quantity than for a corresponding steam-motor.

A gas-engine with 7½-inch cylinder, 14-inch stroke, at 201 revolutions per minute, gave 11.9 indicated horse-power and 7.9 effective horse-power, with a mean pressure of 79 lbs. per square inch, and a consumption of gas of 15.95 cubic feet, or 24 cubic feet respectively.

The mechanical efficiency was 66.4 per cent. of the theoretical work due to the gas.

The cooling water used was 18.73 lbs. per minute, with a rise in the temperature of 40° Fahrenheit.

So-called "gasoline" engines are neither properly gas nor oil engines, and come into consideration in Chapter XXXII., as they use vapour of a highly explosive character.

CHAPTER XXXI.

THE POWER OF THE EXPLOSION OF VAPORIZED MINERAL OIL IN THE OIL-ENGINE.

It is rapidly becoming apparent that in the vaporization and explosion of mineral oil we have before us the most serious competition with steam, or indeed with any other form of "heat-engine." The long-continued labours of Priestman have resulted in perfecting the means of vaporization of crude and low-grade oil to such a degree that the early difficulties experienced in the process have disappeared, and now a number of inventions, differing only more or less in detail, have entered the field.

From the point of view of the user of power it is a good thing that so much attention is being devoted to this subject, for there can be no doubt that a form of motive power, less complicated by outside considerations than steam, is widely needed, and, while the gas-engine is an excellent substitute under certain circumstances of gas-supply, it is either confined to such localities, or needs a gas-making apparatus demanding nearly the same attention as a steam-boiler.

In the oil-engine we have, even in its present stage, which will by no means represent its perfected forms, a power at once independent, needing little attendance and moderately flexible, while the basis of supply for its necessary material is world-wide, and the visible supply tends to increase. The class of machine described in this chapter must not be confounded with the "gasoline" or "vapour" engine which utilizes a volatile and highly inflammable liquid, and is dealt with in the succeeding chapter.

Oil Supply.—The cost of mineral oil at present varies very widely in different countries owing to costs of carriage, short-sighted monopolies, and the action of syndicates, such as that which is doing such harm to the development of industry in Spain.

The cost is to some extent contingent on the method of transport of the material. In the United States of America long lines of pipes have been laid to sea-ports and large towns. Oil is also transported in bulk in vessels' holds and in special tank-cars on railroads. In barrels the resale of an empty 40-gallon barrel will average 3*s*. 4*d*., reducing the cost of oil by about 1*d*. per gallon. Arrangements as to the cheap delivery of the oil should be examined, and if possible made, previous to the purchase of one of these useful engines.

In the case of the larger powers a storage should be provided, preferably in iron tanks, and where several users of power are located in the same place such a storage might profitably be divided between them.

Agriculturists in England are rapidly grasping the advantages of this power for farm purposes in the portable form in which the enterprise of several manufacturers is producing it. The carriage in country districts of the quantity of oil representing a given power is found to be so much less than that due to other fuels that the oil-engine will inevitably displace the steam portable engine to a very large extent when its details and management have become more widely understood. At present it is rather looked upon as a complicated form of the gas-engine, which is a false impression, although it is in many respects very similar to that now well-known machine.

The Operation of the Oil-Engine.—The oil-engine generally consists of the usual cylinder, the work in which is usually confined to one side of the piston, as has been found convenient in most gas-engines. The valve gear, driven by

one or other form of gearing from the crank-shaft, operates admission valves, and also a very small pump which supplies oil to the vaporizer. This apparatus, which is the essential feature, is the subject of a number of ingenious devices and patents. In it the oil is subjected to such a degree of heat, when finely divided in a spray, as completely converts it into a vapour, which is then treated as gas in the gas-engine, and is exploded when mixed with air at a given density or compression.

A lamp is in some cases used to heat the vaporizer when first starting, and this is urged by a small hand-fan or blower generally supplied with the machine. When the engine has made a few turns the heat derived from the explosions is sufficient, unless working at a small proportion of its capacity, to maintain a due temperature in the vaporizing chamber, and the lamp may then be extinguished.

Starting.—The oil-engine is subject to the same disadvantage as the gas-engine in requiring manual force to turn it over its dead-centres at first to give it the necessary start.

This, however, in small powers is not a great matter, and self-starting apparatuses of the same kind as those applied to some of the larger gas-engines may be arranged to work in connection with the oil-engine.

But so long as the supply of oil lasts the machine requires no other attention beyond lubrication, and the leading makers give amply sufficient guarantees of workmanship and material.

The "Cycle."—The "cycle," or recurrence of operations in the cylinder, is now almost universally that known as the four-cycle, by which an impulse is given, at maximum power, every other revolution of the crank-shaft. The number of impulses at full, three-quarter, and half power, thus obtained are to be seen in the diagram of "cycles" in the previous chapter.

Water Circulation.—A supply of cooling water is a neces-

sity, and in the portable form it is conveniently arranged in a tank carried under the machine, but when thus situated below the level of the cylinder a circulating-pump is needed as part of the apparatus.

In the fixed form of engine a natural circulation can be obtained by the use of a tank fixed at a proper level, or by a running supply. The cost of freight upon such a tank may, however, more than outweigh that of a circulating pump.

Adaptations.—The engine is generally constructed upon a hollow base, in which a supply of as much as a week's consumption of oil may be stored, rendering it so self-contained, as well as solid, that very little fixing to foundations is required, it being sufficient, with sizes up to five effective horse-power, to secure it to a wooden floor by coach-screws.

Thus, where fuel of any kind is dear and water is scarce, the oil-engine offers peculiar advantages, especially now that the portable form has become obtainable, in which the whole of the water and oil-supply for a week's running may be transported. Compared with steam, the absence of attendance, and of fire and sparks, together with the general cleanliness of the apparatus, will prove in many cases of great advantage. For pumping in mine headings a number have been employed successfully, and even for rock-boring with a rotary cutter, while others have been applied to hauling purposes and to compressing air for fog-signal stations.

Their use for providing the power for domestic installations of the electric light is a greatly increasing one in Great Britain, and for general agricultural purposes, dairy, sawing, crushing, and mill-driving, they seem to prove quite as satisfactory as any motor.

The various classes of fixed and portable oil-engines on the market, up to the spring of 1894, were neatly classified by the *Engineer* newspaper in its reports of the trials of these machines at Cambridge, which, somewhat modified for the sake of greater clearness, stand as follows:

Classification of the Working Principles of Oil-Engines.

As to Converting the Oil into Vapour.

Class.	Method.	Name.
A	Engines in which the charge of oil is prepared for admission to the cylinder by means of a "SPRAY-MAKER," which forms of it an oil-shower, readily converted into vapour on its entrance to a heater, or to the hot cylinder.	*The Priestman.* *The Griffin.* *Butler's patent* (*partly*).
B	Engines which receive the oil direct into the cylinder, and convert it into a gaseous vapour in an extension of the cylinder open to the piston, by the heat of previous explosions and of compression of the charge.	*The Hornsby-Akroyd.* *The Daimler.* *The Capitaine.*
C	Engines which receive the oil into a chamber or jacket, and convert it into vapour there, admitting it to the cylinder afterwards as required by a vapour valve.	*Butler's patent* (*partly*). *Richardson, Bell & Norris.* *The Trusty.*
D	Engines which receive the oil into a separate VAPORIZER, heated by an oil-lamp, with a forced air-supply, and admission to the cylinder by a vapour valve.	*The Premier.* *The Campbell.* *The Britannia.* *The Crossley.* *The Fielding.*

As to Igniting the Charge.

Class.	Method.	Name.
E	Engines in which ignition of the charge of vapour is effected by an ELECTRIC SPARK.	*The Priestman.* *Butler's patent* (*at starting*).
F	Engines in which ignition is effected by means of an IGNITION-TUBE heated by a lamp or by an ignited oil-spray.	*The Daimler* (*partly*). *The Campbell.* *The Britannia.* *The Crossley.* *The Fielding.* *The Griffin.* *The Premier.* *The Trusty.*
G	Engines in which ignition is effected by the heat of the walls of the cylinder, aided by that produced by the COMPRESSION of the charge.	*The Daimler* (*partly*). *The Hornsby-Akroyd* (*after starting*). *The Butler's patent* (*after starting*). *Richardson, Bell & Norris.*

Essential Features of the Various Forms of Oil-Engines.

The Priestman.—This comes under classes *A* and *E*, being provided with a separate spray-maker, making an oil shower, afterwards heated and converted into vapour on its entrance to the heater. The ignition is by electric spark.

The Butler Patent.—This comes partly under classes A and C and under E as regards ignition.

It is started by means of a small quantity of highly volatile oil, such as benzoline, and, after getting well to work, is fed with heavier oils.

The machine is fitted with a separate mixer and heater combined. This is heated by the passage of the exhaust from the cylinder through its interior. An annular space around the exhaust chamber is used for the passage of the air-supply, which is thus heated before arriving at the injector or inspirator. This is situated in the centre of the exhaust chamber, and is thus also kept hot. The air and oil are thus blown together in a heated condition into a small chamber also surrounded with exhaust vapour, and from thence past a controlling valve operated by the governor to the main inlet valve. On entering the cylinder the charge is fired at first by a bichromate electro-battery, but after working a little at full load the heat of compression joined to that of the cylinder walls and that held by the charge, fires it automatically, and the battery may thus sometimes be cut out of action.

The Griffin Engine.—This comes under classes A and F, and is provided with a large heater in the base of the engine frame, warmed by the passage of the exhaust gases around it. At the end of the heater is a chamber for the admission of extra air through an adjustable valve. The opposite end holds the injector, through which air is supplied from the air-pump at a pressure of about 12 lbs. per

square inch. Some of the oil, contained in a little chamber, finds its way by capillary action up two bent pins in front of another injector, and forms a separate spray inside the ignition tube, which is ignited and thus maintains its temperature.

The main spray-making injector is provided with an oil-valve held up against the supply by a spring. When the governor acts to increase the speed, it admits air under pressure to the upper part of this valve, and thus admits the supply of oil to the suction of the injector.

The Hornsby-Akroyd.—This engine depends for its heat in the vaporizing chamber upon the heat of combustion of the charges, and after once starting, the same heat plus that of compression is used to explode the vapour.

The vaporizing chamber is first heated by two strong lamps forced with air from a hand blower. This independent apparatus is always ready to reinforce the heat if it falls below what is necessary. The oil is injected into the vaporizer at first by a hand pump, and the heat is raised to a point sufficient to explode the resultant vapour. At the junction of the injector and oil-valves with the hot chamber a circulation of water is provided to keep them cool, while the hot chamber is protected from radiation by a jacket or cover. The interior of the vaporizer is provided with a series of ribs of metal, by which the heating surface is increased.

Richardson, Bell and Norris Patents, known also as the "Robey."—This comes under Classes B and G.

The oil is injected in a jet against the surface of the vaporizer, which is an extension of the rear end of the cylinder of an annular form. This throwing of the oil against the heated surface partly vaporizes it, and the vaporization is completed by subsequent heating, accomplished at first by a lamp, and, after getting to work, by the heat due to combustion. The resultant vapour is admitted to the cylinder

by a controlling valve on the back of the chamber. The system thus differs from others, as the vapour is a result partly of the jet and of surface vaporization, the air-passages being so arranged that the air passes over the heated surfaces, carrying the vapour with it. The governing arrangement acts upon the oil supply by reducing it as required.

The Premier (Hamilton's Patents).—This machine comes under Classes D and F. The vaporizing chamber is attached to the end of the cylinder, and contains three valves: an oil-supply valve, a controlling supply valve for the mixed vapour, and an exhaust valve, the two latter being of the mushroom type, and operated by a rocker arm from a cam on the gear-shaft. The governing is effected by cutting out ignitions and opening the exhaust valve.

The oil is fed through the supply valve, which consists of an oscillating plug having a recess in it, and also a little port for the admission of some of the air supply. When a charge of oil enters, an equal quantity of the air is released up an escape pipe, whereby the feed may be visible. The oil then drops on to a plate in the vaporizer, and is there blown upon by the entering air previously heated by passing through a passage around the combustion chamber. The lamp or burner which heats the ignition-tube also heats the bottom of the vaporizer, and its waste products are led back and around its oil- and air-supply pipes, thus making of it a regenerative lamp or burner.

The governor acts by catching the valve-lever in the position of full exhaust and so holding it for one or more turns of the operating cam.

The Trusty (Weyman-Knight Patents). — This comes under Classes C and F.

The vaporizer chamber is the annular space between the combustion chamber and its casing. The oil is fed, drop by drop, on to the top of this hot inner chamber, and, being vaporized, is caused to pass with the air supply over its en-

tire surface on its way to the vapour-control valve, which admits the resultant mixture to the combustion chamber. The exhaust is a simple mushroom lift-valve. The governing is by control both of the oil supply and the vapour valve.

The Campbell.—This engine comes under Classes D and F, its essential feature being the vaporization of the oil by introducing it into a vaporizer with a current of in-rushing air sucked in by the piston through an inverted mushroom valve at the top. The air mixes intimately with two fine jets of the oil also sucked in by the suction, which is regulated by a cock on the oil-pipe. The vaporizer is heated by a lamp underneath.

The Britannia (Root's Patents).—This also comes under Classes D and F, and operates on the system of dropping the oil supply and then directing a heated current of air past it during vaporization. The air is brought round a series of passages in a heating chamber over the ignition-tube and lamp, whereby it is heated before arriving at the oil. There is a little horizontal plunger moving back and forth in the oil-cock. It has a groove in it and gets this groove filled with oil at each reciprocation. The groove comes out into the hot-air passage and the oil is swept off by the air and led as a mixed vapour to the admission valve, and there is a further supply of heated air led into connection with it from a passage or coil in the hot exhaust. The governor acts by altering the movement of the little plunger, which thus increases or decreases the oil supply.

The Crossley.—This machine stands under Classes D and F.

The oil is drawn into the vaporizer by suction together with a little air. The resultant vapour is drawn into the cylinder with a further supply of air, and there fired by an ignition-tube kept hot by a lamp. The governor opens the vapour valve when a charge is required, otherwise the en-

gine gets no charge, and additional regulation is provided by a measuring apparatus for the oil supply, which gives a slightly increased supply for the working charge succeeding an idle stroke.

The Fielding.—This engine comes under Classes D and F.

The air supply is drawn through a heated bent tube situated above the lamp flame. This tube is bent in the form of a reversed capital letter S, and contains a mushroom non-return valve in its lower bend. The suction set up by the piston draws a supply of air in at the upper end. The oil supply is drawn from a little jet at the first bend. The air and oil are vaporized and drawn through the mushroom valve into the lower part, which, being in the lamp flame, is very hot and explodes the mixture when the compression of the return stroke has rendered it inflammable. The governor acts on the non-return valve and on the exhaust valve.

The Daimler.—This engine comes under Class B, and, for ignition, partly under Classes F and G.

Its essential feature is a combustion chamber in which is suspended a bunch of nickel rods or wires upon which the oil is sprayed, and which are heated primarily by a lamp underneath, though after working some time the heat of explosions maintains them at a red heat.

The Capitaine.—This machine stands under Class B, but its ignition arrangements have been undergoing some modifications so that it is difficult to fix their description.

The vaporizer is provided with a self-acting inlet air-valve through which the suction of the piston draws a supply of air from the atmosphere, mixing it with the vapour formed from the jet of oil injected by the oil-pump into the vaporizer. The whole volume when compressed on the back stroke of the piston reaches an explosive condition and temperature, aided in the standard pattern by the heat of a burner under the vaporizer.

An ingenious device is a little valve in the oil-pipe closed or opened by a lever resting on the vaporizer, the expansion or contraction of which affects its position, and thus its own temperature is a regulator of fresh supply of fuel. The governing device is in control of the oil-pump, and also holds open the exhaust valve.

Tests of Oil-Engines.—The trials of oil-engines made by the Royal Agricultural Society at their Cambridge Show in 1894, have afforded much valuable information on the subject of their consumption of oil. Seven fixed and four portable machines were subjected to tests of two hours each at full and half loads, and ran for four hours free of any load. The results appear on the following page, as regards those engines which went through the tests under the stipulated conditions. Several of the other machines briefly described above, from one cause or the other, took no part in the competition, and the results therefore cannot be accepted as entirely conclusive on the subject.

Economy.—Comparative accounts of the cost of running a steam and an oil-engine, such as is published by some makers to the advantage of the latter, may be accepted with reserve, as such accounts can exhibit no more plainly than common sense will already know, the fact that the oil-engine does not require the entire attention of a skilled driver, and that it costs less to haul 1 ton of oil than 5 tons or so of fuel. The comparative local cost of the two materials will be needed to decide the matter, and if oil be obtainable and of reasonable price the oil-engine will not require much recommendation. The following practical uses to which oil-engines have been put will serve to show better than estimated comparisons what may be done with the machine.

In a careful test made by Mr. Suete in 1893, during a run of 17 hours 38 minutes, the engine gave 5.621 average *effective* horse-power, at an average speed of 225 revolutions

Results of Trials of Oil-Engines by the Royal Agricultural Society of England, 1894.

FIXED ENGINES.

Type.	Classification. (See Table page 219.)	Revolutions per Minute.	Size of Cylinder. Bore.	Size of Cylinder. Stroke.	Effective Horse-Power at Full Load.	Oil Used per Effective Horse-Power per Hour at Full Load.	Effective Horse-Power at Half Load.	Oil Used per Effective Horse-Power per Hour at Half Load.	Effective Horse-power Used to Run the Engine alone.	Cost of Engine.
			Inches.	Inches.		Lbs.		Lbs.		
The Britannia	D and F	251	7⅛	13	6.64	1.508	4.47	1.51	....	£120 = $600
The Campbell	D and F	202	....	....	4.48	1.20	2.74	1.36	1.98	£110 = $550
The Crossley	D and F	201	7	15	7.3	.82	3.75	1.32	3.29	£110 = $550
The Fielding	D and F	156	7¾	14	5.88	2.38 out of adjustment	3.76	......	....	£150 = $750
The Hornsby-Akroyd	B and G	238	10	15	8.47	.98	4.48	1.51	3.5	£160 = $800
The Premier	D and F	163	8¼	15	6 62	1.15	3.50	1.66	2.5	£112 = $560
The Trusty	C and F	262	6¾	13	4.95	1.12	2.56	1.49	2.16	£125 = $625

PORTABLE ENGINES.

Type.	Classification.	Revolutions per Minute.	Bore.	Stroke.	Effective Horse-Power at Full Load.	Oil Used per Effective Horse-Power per Hour at Full Load.	Effective Horse-Power at Half Load.	Oil Used per Effective Horse-Power per Hour at Half Load.	Effective Horse-power Used to Run the Engine alone.	Cost of Engine.
The Campbell	D and F	182	8⅛	16	9.7	.98	4.97	1.13	3.07	......
The Crossley	D and F	207	8⅛	18	9.95	.90	5.03	1.97 out of adjustment	4.75	......
The Butler	A and C	193	10⅛	16	13.95	1.22	6.82	1.37	5.82	......
The Hornsby-Akroyd	B and G	196	12	16	10.52	1.15	5.98	1.21	4.30	......

The oil used by the lamp is included in each result.

per minute, using during the above period 10 gallons of oil, being 1.22 horse-power per pint of refined lamp-oil (of 120 test) at 6*d.*, or 12 cents, per gallon.

A 4½ effective horse-power oil-engine, in 9 hours ground 70 bushels of fine meal with stones 3 feet 10 inches in diameter.

An account of a month's running of an engine was made by a firm who had replaced a steam-engine with this motor. The steam-engine had been a 10-inch cylinder, with a Cornish boiler, and had used 5 tons of coal per week at 15*s.*, say $3.75, per ton, with a driver's wages at £1, say $5, per week. This resulted in a cost of 15*s.* 10*d.*, say $3.95, per 10 hours' work. The steam plant being replaced with two coupled oil-engines of a capacity of 16 effective horse-power *each*, the same duties were performed at a cost for oil of 5*s.* 11*d.*, say $1.48, for 10 hours, and about 6*d.*, say 12 cents, for man's time in attending the machines.

As regards continuous running, a machine has run 56 hours without stop, in drying hops, or 494 hours in 23½ days.

In small electric-lighting plants the oil-engine will do good work. So small an engine as 1½ effective horse-power is giving 200 candle-power in 15 lamps at Rochester.

From the above particulars it will be evident that the opening remarks upon this subject are sufficiently justified by the simplicity of the system; and upon the question of economy, what follows will indicate clearly the advantages the oil-engine possesses over other powers *where a supply of cheap mineral oil can be secured.*

It is upon the cost of this supply, naturally, that the whole question of its adoption hinges.

Comparative figures of cost per horse-power should only be accepted upon local prices of oil and coal or other fuels.

The oil to be used may be, in most of the above-described engines, the crude mineral-oil, weighing 8½ lbs. per im-

perial gallon, with a flashing point of 200° to 220° Fahrenheit. The Robey engine will utilize a still heavier class, not less than 240° test, and the Trusty will work with creosote. But any of the engines will run with refined lamp-oil if the former be unobtainable. This should not be lighter than 8 lbs. per gallon. The cost of the supply thus varies considerably and will be found to stand in England from *4d.*, say 8 cents, per gallon, to *6d.* and *6½d.*, say 12 or 13 cents, per gallon.

Even at the latter price small engines may be run at a cost of only .77 of a penny, or say about 1½ cents, per effective horse-power per hour, and a careful trial by Mr. W. Beaumont, A.M.I.C.E., with oil at *4d.*, say 8 cents, per imperial gallon, gave the following results :

	Cost per Indicated Horse-power.	Cost per Effective Horse-power.
Full load	.348 of a penny.	.41 of a penny.
Half load	.342 " "	.565 " "
Without any load	.406 " "	——

Equal to about two-thirds of a cent to a little over one cent.

In this trial, the engine used 2¼ lbs. of oil per hour when running free of any load, which was equal to an effect of 2.74 effective horse-power.

Such results will compare favorably with the best performances of the gas-engine, unless the latter be run under exceptionally cheap sources of supply, such as the Dowson apparatus, or, as is the case in some North-England towns, where the cost of town service has been reduced by skilful management to below *2s.* = 50 cents per 1,000 cubic feet. In the United States the price of city gas is generally above $1 per thousand, and frequently above $1.50, and similar prices are customary on the Continent. Under equal circumstances, however, the oil-engine will retain the ad-

vantage of independence of a local-supply company and of portability.

GENERAL PARTICULARS OF OIL-ENGINES.

Effective Horse-Power.	Revolutions per Minute.	Size of Belt Pulley in Inches. Diameter.	Width.	Floor-Space Required. Length.	Width.	Approximate Weight.	Cost of Engine.	Cost of Water-Tank with Connections 5 feet from Engine.	Extra Cost to Make Engine Portable. Simply Mounted on Wheels.	Fitted on Tank Body, Wheels under Carriage and Shafts.
		in.	in.	ft. in.	ft. in.	cwts.				
1	250	10 ×	5	4 5 ×	2 9	12	£70 $350	£4 15 0 $23.75	....	....
1½	250	12 ×	5	6 3 ×	3 6	14	£78 $390	£4 5 0 $21.25	£8 5 $41.25	....
2	250	12 ×	6	5 8 ×	3 2	15	£85 $425	£5 10 0 $27.50	....	....
2½	250	15 ×	6	6 4 ×	3 6	20	£90 $450	£5 5 0 $26.25	£8 15 $43.75	....
3½	225	18 ×	6	7 2 ×	3 9	22	£110 $550	£6 10 0 $32.50	£11 15 $58.75	£42 $210
5	210	20 ×	7	8 4 ×	4 6	26	£125 $625	£8 10 0 $42.50	£14 15 $61.25	....
6½	205	20 ×	8	8 6 ×	4 6	33	£139 $695	£8 7 6 $41.88	£14 5 $61.25	£52 $260
7	240	21 ×	9	7 6 ×	4 4	38	£145 $725	£9 0 0 $45	....	....
8	205	24 ×	9	9 2 ×	5 0	42	£160 $800	£9 15 0 $48.75	£18 10 $92.50	£55 $275
9	240	24 ×	12	9 6 ×	4 9	46	£175 $875	£10 10 0 $52.50	....	....
9½	200	24 ×	12	9 4 ×	5 0	48	£180 $900	£10 15 0 $53.75	£18 10 $92.50	£63 $315
10	240	24 ×	12	10 3 ×	4 9	49	£200 $1,000	£12 10 0 $62.50	....	....
12½	200	27 ×	12	9 9 ×	5 4	....	£212 $1,060	£17 0 0 $85	£21 10 $107.50	£73 $365
14	220	30 ×	12	10 3 ×	5 6	....	£239 $1.150	£18 0 0 $90	....	....
16	200	30 ×	13	10 3 ×	5 8	....	£247 $1,335	£19 0 0 $95	£21 10 $107.50	£84 $420
19	200	36 ×	13	10 6 ×	6 9	....	£278 $1,390	£23 0 0 $115	£24 0 $120	£95 $475
20	220	42 ×	15	11 0 ×	7 0	....	£300 $1,500	£28 0 0 $140	....	....
25	160	48 ×	15	12 6 ×	7 9	....	£330 $1,650	£34 0 0 $170	£27 10 $137.50	....

Most manufacturers charge extra for exhaust pipe and silencing-box, the cost varying from £1 10s. to £9, say $7 to $45 ; also for foundation bolts, from 8s. to £1 10s., say $2 to $7.50, if they be necessary. In other respects the costs are inclusive of all necessary parts.

The weight of complete portable oil-engines, with tanks and carriages, runs about the same as portable steam-engines of equal power.

CHAPTER XXXII.

THE VAPOUR OR GASOLINE ENGINE.

A FORM of motor known as a "gasoline" engine is finding extensive adoption in America, which does not appear to possess some of the chief merits of the genuine oil-engines described in the previous chapter, especially as regards the use by the latter of low-grade and safe mineral oil. On the contrary, these gasoline machines make use of a highly volatile liquid of only 74° test, costing about 10 cents a gallon in barrels. If such material is used at all, it should be stored in some safe place quite outside any buildings, and a supply brought by pipe to the engine, which is fitted with an "evaporator" or chamber in which the liquid may safely vaporize and through which the cold air is drawn to the cylinder. The resulting mixture is fired by an ignition-tube, much as a gas-engine does, the governor acting upon a throttle on the inlet-pipe, and the tube being heated by a jet of the "gasoline" underneath it.

The electric spark is sometimes applied for the purpose of ignition where the presence of a "gasoline" burner is objectionable. In other respects the machine is similar to a gas-engine and employs a water circulation of a similar character. It is claimed for these engines that they will run for ten hours on a consumption of about one gallon of gasoline per horse-power, or about one cent per horse-power per hour. This is no better than can be accomplished with a safer material, and the dangers attendant upon the use of this system are illustrated by the regulations of a well-known fire-insurance office with reference to them. Per-

mission is given for the use of the engine in an insured building "only under the following restrictions and conditions to be observed by the assured, viz.: That at no time shall there be to exceed one gallon of gasoline to be contained in metal reservoir within said building or additions, free from leak and away from artificial light or heat. The reservoir to be filled and the gasoline handled by daylight only. The supply-tank to be of iron and located outside of building and under ground, and to hold not to exceed two barrels."

Notwithstanding, a large number of these engines are now at work in many small industries throughout the States, especially in operating elevators and printing presses. Their cost and dimensions are about as follows :

GASOLINE OR VAPOUR ENGINES.

Effective Horse-Power.	Revolutions per Minute.	Floor Space Occupied.		Weight.	Cost.
		Long.	Wide.		
		Ft. In.	Ft. In.	Lbs.	
2½	300	5 0	3 6	1,600	£80= $400
3½	280	5 8	4 0	3,000	£100= $500
5½	260	6 8	4 6	4,500	£140= $700
7½	250	7 0	4 9	5,000	£160= $800
10	240	7 6	5 0	6,000	£220=$1,100
15	230	8 0	6 0	6,700	£280=$1,400

The Naphtha Engine.—This apparatus is a prime motor, deriving its force from the use of the lightest form of refined petroleum, and has been found a very handy little apparatus for driving launches. Strictly speaking, it is no more than a condensing steam-engine, inasmuch as the naphtha is used in place of water, and is turned into an expanded volume of vapour by the use of heat. The fire is, in these launches, also fed by the use of a portion of the same liquid, the objects attained being the use of but one

material on board the boat, very rapid raising and lowering of pressure, and condensation by a passage of the exhausted vapour in a copper coil, or tube, in contact with the sea-water. Equally good results may be attained in driving launches by the use of the heavier oils in the oil-engines now made in marine forms by Priestman, Daimler, and others. For the exclusive purpose of launch-driving the apparatus is good and has a future, but not so for land purposes. The vaporous liquid is highly inflammable, and its carriage is prohibited in certain countries and upon the best lines of vessels.

The vapour or gasoline system cannot be recommended as a motive power in comparison with the oil-engine, using oils of a low grade with complete safety.

CHAPTER XXXIII.

THE HOT-AIR ENGINE.

THIS heat-engine was, when introduced in 1820 by Sterling, trumpeted as the future rival of steam, and has continued to be spasmodically vitalized by one or other of the ingenious inventors who have spent their energies in trying to overcome its inherent defects.

The apparatus is based upon the expansion of common air under heat, its alternate contraction and expansion being effected by its transference to and from a heated chamber.

In the work of driving the piston of an engine, however, the heat contained in air is so rapidly parted with that all the efforts of the various makers of these machines have not succeeded in placing engines of any serious power upon the market.

The Rider hot-air engine is a neat form of the apparatus, designed chiefly for domestic pumping duties, and others have been made by Bailey, Buckett, Tyler, and Robinson, but without much degree of success, except for the small powers and duties above-named.

In such a connection, however, their use is highly economical and successful, there being in use, it is said, upwards of ten thousand of the Rider type alone and some six thousand of that known as the Ericsson.

These little machines can use coal—preferably anthracite—coke, wood, gas, oil, or gasoline as fuel, and can be attended by any unskilled person, domestic servants having many of them in charge. For the special purpose of domestic pumping, up to 3,000 gallons per day, the hot-air

engine comes into competition with any other class of prime motor, and may even surpass in advantage the use of a windmill, which often suffers from the comparative disadvantage of disfiguring its surroundings and liability to damage in storms. On the other hand, although the hot-air engine requires—comparatively with steam—little supervision and attention, it nevertheless needs a certain amount, but may, when heated with gas or oil burners, fairly meet this difficulty and require no attention whatever for hours at a stretch, except some intelligence in starting the burner into operation. It is easily adapted to domestic installations, requires little or no foundation, and it will stand, for instance, in a cellar and pump water to tanks in floors above. For irrigation of farm and vine lands it answers admirably, and is largely used in America for supplying water to road-side tanks for locomotives. A similar application is for the supply in watering town streets by placing several tanks with these engines at different points in a town, the necessary attention being given by the men when filling their carts.

Engines for general power purposes have been made for many years on the Wenham system of a single-acting cylinder, receiving heated air and gas direct from the fuel, up to 40 inches diameter of cylinder, the proportions and cost of this type being as follows :

HEATED-AIR ENGINES. WENHAM TYPE.

Effective Horse-Power.	Diameter of Cylinder.	Revolutions per Minute.	Cost.
	Inches.		
½	12	140	£75 = $375
1	16	120	£100 = $500
2	20	110	£144 = $720
3	24	100	£190 = $950
5	30	90	£277 = $1,385
10	40	90	£370 = $1,850

In these machines the heated supply is taken direct from contact with the fuel in a closed combustion chamber, and therefore the state of the fire requires careful attention at all times.

The largest practical size of hot-air engine was one of Stirling's own make, which worked for many years in the Dundee foundry, giving 45 indicated horse-power.

In the Rider machine, which is made in sizes from half to three horse-power, the working piston is not exposed to the direct action of the fire, and, as has been pointed out, the minimum of attention is necessary. As in this and other types a certain amount of water is necessarily employed to cool the cylinder, it is manifest that the most economical adaptation of the machine is its combination with a pump as a pumping-engine, when part or all of the water raised by it may be made to serve the purpose of cooling on its passage through the machine.

The machine is then arranged with the pump on one side of a fly-wheel and the cylinder and fire-grate on the other, which may be used also to drive a belt.

GENERAL PARTICULARS OF HOT-AIR PUMPING ENGINES. RIDER TYPE.

Diameter of Cylinder.	Revolutions per Minute.	Size of Water Pipes.	Consumption of Fuel per Hour.			Space Occupied, in Inches.	Weight.	Cost with Pump.	Cost with Deep-well Pump.
			Anthracite Coal	Lamp Oil.	Gas.				
ins.		ins.	lbs.		cu. ft.	high wide lg.	lbs.		
4	120–160	3/4	2	1 pint.	10	46 × 18 × 25	500	£30 = $150	....
5	100–160	1	3	1 qt.	20	60 × 26 × 33	1,050	£45 = $225	£48 = $240
6	100–120	1 1/2	4–5	2 qt.	50	72 × 28 × 40	1,800	£60 = $300	£63 = $315
8	100–120	2	6–7	......	60	86 × 29 × 47	3,200	£80 = $400	£84 = $420
10	80–110	2 1/2	7–8	......	80	93 × 32 × 52	3,600	£100 = $500	£104 = $520

The cost of oil-tank and burner for above varies from £2 = $10 to £3 = $15. The above are sizes made in America. In England, 6-inch and 10-inch cylinder engines,

weighing respectively 1,200 and 2,600 lbs., cost £45 and £75.

These hot-air engines will pump water up to 300 feet about as follows:

Diameter of Cylinder.	Imperial Gallons Lifted.					
	50 ft.	100 ft.	150 ft.	200 ft.	250 ft.	300 ft.
4 inches	150					
5 "	290	165				
6 "	830	660	415	250		
8 "	1,660	1,000	750	415		
10 "	2,900	1,660	1,250	830	580	415

The Ericsson engine has a single-acting cylinder operating on a rocking-beam connected to a crank and fly-wheel laid out beside the cylinder. The working parts are not exposed to flame, and, like the Rider, its best adaptation is as a pumping combination.

It is made in four sizes, as follows:

HOT-AIR ENGINES AND PUMPS. ERICSSON TYPE.

Diameter of Cylinder.	Consumption of Fuel per Hour.		Space Occupied. Inches.	Weight.	Cost.	Cost with Deep Well Pump.
	Gas.	Anthracite Coal.				
Inches.	cub. ft.	lbs.	high wide long	lbs.		
5½	12	2½	50 × 29 × 16	400	£25 = $125	....
6	18	3	54 × 42 × 24	600	£36 = $180	£38 = $190
8	25	3½	66 × 48 × 26	900	£45 = $225	£47 = $235
10	60	5	66 × 52 × 38	1,600	£60 = $300	£63 = $315

SECTION VII.

CHAPTER XXXIV.

THE STORAGE OF POWER BY ELECTRICITY AND RE-USE OF SAME.

WHILE electricity is not a prime motive power, for which it is often mistaken by uninformed enquirers, it is, especially in its economical capability for storage of current and conveyance of power thereby, at will, to a distance, so intimately connected with the selection of the best power to suit certain circumstances that a section must here be devoted to its consideration.

The respective advantages of other means of conveying power require a volume of special description, but electricity stands on a different basis as regards this facility for unlimited storage, and also in the existence in most large towns of electric-power supply stations, whence current may be obtained at commercial rates, much as gas is supplied.

The first fact to be grasped is that electricity must be generated by force or power of some kind. Chemical production may be put out of consideration, presenting too many disadvantages for practical use except for very small operations.

The production of electricity is commercially conducted by means of the so-called dynamo, a machine which only requires rotation in one direction continuously.

Any motive power may be employed for the purpose, preferably those in which the speed and power are subject to the least fluctuations possible. Where these necessarily

exist special arrangements are necessary to overcome the fluctuations resulting in the force of the current generated.

This is best accomplished by the use of what are known as accumulators, which receive the current in a fluctuating form, but give out a resulting steady flow. They are boxes containing alternate frames or plates of various compositions, chiefly based on lead, which being immersed in dilute sulphuric acid, one set are decomposed by the action of the electric current and deposited upon the other.

On forming a reverse circuit of outlet from these plates a lesser reverse action takes place, the deposited metal going back to its original plate, giving out a feeble current in so doing, until the original equilibrium is established.

In order to obtain a forcible current a number of these boxes and plates have to be coupled together successively to one another, or in the manner known to electricians as "in series," each thus adding its quota to the other till the required amount of force is reached. These general remarks lead up to the following practical facts.

The Storage of Electricity and Conveyance of Power Thereby.—In order that the non-technical reader may understand the conditions under which the effect known as electric energy is produced, stored, and re-used it is necessary to grasp the meaning of the terms used by electricians. These somewhat uncouth words are not difficult to commit to memory, and answer quite as well as any other the purpose of definition. Those with which alone we are concerned here are four in number :

A Volt, is a term used to define electric *pressure*, and is practically applied to the electric-current as pressure by square inch is by engineers to steam. It is also known as electric - motive-force, frequently written E. M. F. for convenience, also potential, and is constantly spoken of as tension, or "voltage." This in-

terchange of terms is to be regretted. Here the words volt, and voltage are used.

Ampères, are the quantity of current, and may be compared with the cubic quantities used in defining steam or water; it is frequently written "current." As quantity multiplied by pressure gives us in all calculations a definition of power, ampères multiplied by volts give us

Watts, or volt-ampères, which are practically the foot-pounds by which we define a horse-power. The Watt is an arbitary quantity of 1 ampère at 1 volt, of which 746 equal a horse-power of 33,000 foot-pounds, and thus constitutes the means of comparing electric energy with other powers.

The Ohm, is the term to define the resistance of conductors or wires to the passage of electricity. It answers to the friction opposed to liquids passing through a pipe. The standard ohm is the resistance due to a copper wire $\frac{1}{16}$ of an inch diameter $\times$ 129 yards long.

As every conductor offers some resistance to the flow of electricity, the larger the wire the less will be its resistance.

Similarly the shorter the wire the less will be its resistance.

It is naturally foreign to the purpose of this book to proceed closely into descriptions of the action and theories of electricity. The foregoing terms cover all practical applications, and enable any one who commits them and their meaning to memory to make necessary calculations for the adaptation of electric installations.

Let it be clearly understood, however, that electric energy may be utilized at any number of volts, according to the construction of the dynamo, but this cannot be very widely varied once the machine is made. It does vary a little according to the speed at which the dynamo is driven, but this is a feature to be avoided. Then, too, its volts may be

fixed at a higher amount than necessary, and reduced by the insertion in its circuit of a "resistance frame." This is a wasteful arrangement, equivalent to raising steam to a high pressure to let it down again. It is only of value in cases where a dynamo is to charge accumulators and afterwards work in unison or parallel with their output, which is liable to fall to a somewhat lower number of volts.

In estimations of power of electric energy it is always necessary to bear in mind those losses which occur in all mechanism, due to friction, imperfections, and leakage.

Thus, 10 effective horse-power employed to rotate a dynamo will not produce full 10 effective horse-power of electricity, but a less amount, which may safely be taken at 80 per cent., or 8 effective horse-power, and is so taken in my tables and calculations.

Inversely, 8-horse power of electricity given out by a dynamo requires more than 8 effective horse-power to produce it.

Similarly, the conduction of the current over a wire involves a certain loss by friction, which must be allowed for, and of which tables are given, rendering elaborate calculations unnecessary.

Then, the supply of a given quantity of electricity, say a number of Watts, to a motor will not result in an exactly corresponding effective horse-power, but an amount less by from 10 to 15 per cent., which in my tables I have for entire security taken at 20 per cent.

In the case of storage cells, or accumulators, we have rather different circumstances. There is an initial amount of work developed in the process of "charging" them, that is, of decomposing them.

This results in a total output of less amount, but the output can be made use of at a higher rate of power than the original power, *but for a shorter period.* Thus we may use 25 ampères during 10 hours to "charge" a set of accumu-

lators, while we may when they are "charged," use out of them 50 ampères for 3 to 4 hours; and so having only a small motive force we may employ it for a long period in order to produce a much larger force for a shorter period. It is this facility which lends so much value to the storage of electricity.

We have now before us all the essential features of electric arrangements, and the following facts and tables will enable decisions to be arrived at as regards powers.

Dangerous shocks are not to be got at the ordinary number of volts from 110, 105, 100, 85, 65, 60 and 50.

Dangerous shocks are to be received over 200 volts.

Shocks of any kind are unknown in properly insulated arrangements.

Danger by fire may be entirely avoided by similar means. Fire can only arise by the leakage of electric current, when sparking may occur in its passage to some other point, and set woodwork on fire, or explode accumulations of gas and air.

Electricity is incapable of explosion of any kind.

A dynamo is extremely simple to manage and keep in proper order by reasonable attention.

An electric motor is practically a dynamo reversed.

The great increase in the number and size of electric power stations in towns has led to a wide use of motors driven by the current taken from the mains, and for many purposes no better form of motive-engine could be adopted. The charges for current have, however, stood in the way of the installation of electro-motors, and although some companies are now charging a reduced rate for power current taken in day-time, there still remains a great reduction to be effected before electric operation of machinery can be made to compete with other motive engines. The superior advantages of the system, such as cleanliness, quietude, high speed, and regularity, may, and do frequently, outweigh the question of cost. Before deciding upon the system it will

be necessary to examine the proposed charges, and also look into the character of the power-supply station and its record as to break-downs. Used in conjunction with electric-lighting, the cost of connections and wires may be spread over the two.

Electric incandescent lamps require the following currents:

Each 8-candle power, 35 watts; each 16-candle power, 60 watts. Thus each 16-candle power lamp takes about $\frac{1}{12}$ of an electric horse-power.

One 16-candle-power lamp may be taken to light from 60 to 100 square feet of floor space in ordinary rooms.

Large incandescent lamps are made from 100-candle-power upward, and require about 1 indicated horse-power per 160-candle-power.

Clear glass absorbs about 10 per cent. of the light, ground glass from 30 per cent. to 50 per cent.

Winding of Dynamos for Different Work.—A compound-wound dynamo should be used for incandescent lighting, or for incandescent and arc lights in combination, or for arc lighting in parallel.

A series-wound dynamo is best for arc lighting in series.

A shunt-wound dynamo may be used for charging accumulators, or for depositing work.

Dynamos.—As will be seen from the following table, dynamos require to be driven at fairly high speeds, and if the speed be reduced a larger size of machine must be employed to obtain an equal output.

Thus it becomes more economical in first cost to drive a dynamo by belting, from counter shafts, or a large fly-wheel, than by means of an engine coupled direct to the machine, in which case either a very high-speed engine must be employed, requiring care, and probably giving very low economy in working, or the speed of the two must be put at a lower figure. Therefore, except, for confined spaces, as on

board ships, or where simplicity of arrangement, and freedom from possible breakage of belts is more of an object than first cost, a dynamo will be best driven by belt.

Such machines are tabulated here.

DYNAMOS FOR ORDINARY PRESSURES UP TO 120 VOLTS.
SERIES, SHUNT, OR COMPOUND.

Current in Watts.	Effective H.-P. Required to Develop Full Output.	Revolutions per Minute.	Number of 16-Candle-power Lamps Supplied.	Size of Pulley.		Cost of Dynamo.	Cost of Extra Bearing and Fly-wheel.
				Diam.	Width.		
				Inches.	Inches.		
1,000	1.75	1,500	15	4	3	£28= $140	£2= $10
2,000	3.5	1,400	30	6	4	£36= $180	£4= $20
3,000	5	1,300	50	7	4	£50= $250	£5= $25
5,000	8.5	1,200	85	8	5	£60= $300	£6= $30
6,000	10	1,100	100	9	5	£70= $350	£7= $35
9,000	15	1,000	150	10	6	£100= $500	£10= $50
12,000	20	900	200	11	7	£125= $625	£12= $60
15,000	25	850	250	12	8	£150= $750	£15= $75
18,000	30	800	300	14	8	£165= $825	£18= $90
21,000	35	750	350	14	8	£180= $900	£21=$105
24,000	40	700	400	16	9	£200=$1,000	£24=$120
30,000	50	650	500	16	9	£250=$1,250	£30=$150
40,000	65	600	650	18	10	£300=$1,500	£40=$200
50,000	80	550	800	18	10	£350=$1,750	£50=$250
60,000	100	500	1,000	21	12	£450=$2,250	£60=$300

Where the dynamo is driven by an irregular motive power, such as a small gas- or oil-engine, or a badly governed steam-engine, a fly wheel should be used on the dynamo shaft which will aid in correcting the irregularities. The cost of this, and of a bearing to afford proper support is given above.

Cables.—The loss of power per 100 yards of cable at different voltages is as follows :

Volts..........	100	200	300	400	500	600	700	800	1,000
Loss per cent...	2.5	1.25	.83	.625	.5	.416	.357	.312	.25

Naturally these figures lead to the conclusion that the higher the voltage the more economical the conveyance, and such is indeed the case. These higher voltages are, however, dangerous to human life if contact is accidentally made with them, and therefore can only be used with highly insulated wires, which cost much more than the bare wires which may be safely used at 100 to 120 volts. Great divergence of opinion exists as to the limit of safe voltage. In England, it is customary to regard all over 200 volts as approaching the dangerous limit. In America, tensions of 400 volts are constantly used on naked wires in towns.

The opposite table of power-conveying capacity of cables, with cost per 1,760 yards' run, will afford the necessary information for a selection of what is suited to given distances. The cost is liable to fluctuation with the price of copper.

PARTICULARS OF ELECTRO-MOTORS.

Approximate Revolutions per Minute.	Size of Pulley.	Width of Face.	Power Effective.	Price.	
				Motor Complete.	Sliding Bed-Plate.
1,500	4	3	1	£28 = $140	£1 10 = $7.50
1,400	6	4	2½	£36 = $180	£1 15 = $8.88
1,300	7	4	4	£50 = $250	£2 = $10
1,200	8	5	6¼	£60 = $300	£3 = $15
1,100	9	5	8	£70 = $350	£3 10 = $17.50
1,000	10	6	12	£100 = $500	£4 = $20
900	11	7	16	£125 = $625	£4 10 = $22.50
850	12	8	20	£150 = $750	£5 = $25
800	14	8	24	£165 = $825	£5 10 = $27.50
750	14	8	28	£180 = $900	£6 = $30
700	16	9	32	£200 = $1,000	£6 10 = $32.50
650	16	9	40	£260 = $1,300	£7 = $35
600	18	10	53	£300 = $1,500	£9 = $45
550	18	10	66	£350 = $1,750	£12 = $60
500	21	12	80	£450 = $2,250	£15 = $75

Motors.—Electro-motors are practically dynamos reversed, that is their construction is exactly the same, but

COPPER CABLES CONVEYING ELECTRIC FORCE AT DIFFERENT PRESSURES OR VOLTS.

Size of Cable.			Area in Square Inch of all Wires United.	Ampères Carried (at a Density of 1,000 per Square Inch).	Electric Horse-Power Carried by the Cable at Different Voltages.									Cost of Cable per 1,760 Yards, or English Mile.				
Number of Wires.	Diameter of Wires composing Cable.													Bare Copper up to 200 Volts.	Insulated with Rubber, Tape, and Braid, up to		Insulated for Damp Places.	Lead Covered for Under-Ground.
	Standard Wire Gauge.	Decimals of an Inch.			100 Volts.	200 Volts.	300 Volts.	400 Volts.	500 Volts.	600 Volts.	700 Volts.	800 Volts.	1,000 Volts.		500 Volts.	1,000 Volts.		
7	20	.036	.0072	7.2	.841	1.69	2.54	3.38	4.2	5.0	5.8	6.7	8	£7 $35	£32 12 $163	£33 16 $169	£36 $180	£49 10 $247.50
7	18	.048	.0128	12.8	1.38	2.77	4.16	5.55	6.9	8.2	9.6	11	13	£13 10 $67.50	£48 8 $222	£50 12 $253	£54 $270	£66 10 $322.50
7	17	.056	.0174	17.4	2	4	6	8	10	12	14	16	20	£19 $95	£62 $310	£63 $315	£73 10 $367.50	£88 $440
7	16	.064	.0229	22.9	2.69	5.38	8.08	10.77	13.5	17.3	18.8	21.5	26	£20 10 $102.50	£76 10 $382.50	£79 $395	£83 $415	£105 $525
7	15	.072	.0289	28.9	3.28	6.56	9.84	13.12	16.4	19.6	22.9	26.2	32	£26 $130	£92 $460	£94 10 $472.50	£101 $505	£126 $630
7	14	.080	.0356	35.6	4.18	8.37	12.56	16 75	20.9	25	29.2	33.4	41	£33 $165	£107 $535	£110 $550	£118 $519	£143 $715
19	17	.056	.0479	47.9	5.63	11.27	16.9	22.54	28.1	33.7	39.4	45	56	£51 $255	£137 $685	£140 10 $702.10	£152 $760	£182 $910
19	16	.064	.0624	62.4	7.34	14.68	22.02	29.36	36.1	44	51.6	58.7	73	£64 $320	£173 $865	£178 $890	£193 10 $967.50	£229 $1,145
19	15	.072	.0789	78.9	9.28	18.56	27.84	37.12	46.4	55.4	64.9	94.2	92	£79 $395	£212 $1,060	£218 $1,090	£238 $1,190	£281 $1,405
19	14	.080	.0973	97.3	11.44	22.19	34.33	45.78	57.3	68.6	80	91.5	114	£105 $525	£258 $1,290	£263 $1,315	£281 $1,405	£331 $1.655
19	13	.092	.1282	128.2	15.08	30.16	45.24	60.32	75.4	96.4	105.5	120.6	150	£136 $680	£336 $1.680	£341 $1,705	£360 $1,800	£428 $2.140
19	12	.104	.1647	164.7	19.37	38.75	52.18	77.5	96.8	116.2	135.6	154.9	193	£181 $905	£414 $2,070	£422 $2,110	£466 $2,330	£532 $2,660

they rotate by the reception of current. The current is conveyed to them by cables or simple wires. The sections of these wires varies with the power carried, and naturally, the larger they are the less loss of power occurs from internal resistance. About $2\frac{1}{2}$ per cent. is thus lost per 100 yards of distance at a tension of 100 volts in cables of good proportions and of a moderate first cost. Loss further occurs in the motor due to leakage and to the force necessary for its own rotation. This is surprisingly small, and in many tests has proved as little as 10 per cent.

TABLE OF THE CONVERSION INTO ELECTRICITY OF EFFECTIVE HORSE-POWERS OF AN ENGINE, WHEEL, OR OTHER MOTIVE POWER, THE DEVELOPED ELECTRICITY DRIVING A MOTOR.

Effective Horse-Power of Engine or Turbine.	Corresponding Watts.	Watts given out by Dynamo 20 p. c. less than Total.	Nearest Size Dynamo Units of 1,000 Watts.	Cost of Dynamo.	Watts used by Motor, being $2\frac{1}{2}$ per cent. less than Dynamo gives.	Effective Horse-Power given by the Motor, being 20 per cent. less than it receives.	Cost of the Motor.
1	746	596.8	1 unit	£28= $140	582	$\frac{465.6}{746}=.624$	£28= $140
4	2,984	2,387	3 unit	£50= $250	2,327	$\frac{1862}{746}=2.5$	£36= $180
5	3,730	2,984	3 unit	£50= $250	2,910	$\frac{2328}{746}=3.12$	£50= $250
7	5,222	4,177	5 unit	£60= $300	4,074	$\frac{3259}{746}=4.36$	£55= $275
10	7,460	5,968	6 unit	£70= $350	5,820	$\frac{4656}{746}=6.24$	£60= $300
12	8,952	7,161	8 unit	£90= $450	6,984	$\frac{5587}{746}=7.48$	£70= $350
15	11,190	8,944	10 unit	£110= $550	8,730	$\frac{6978}{746}=9.36$	£95= $475
20	14,920	11,936	12 unit	£125= $625	11,640	$\frac{9312}{746}=12.48$	£100= $500
24	17,904	14,322	15 unit	£150= $750	13,968	$\frac{11174}{746}=14.96$	£120= $600
25	18,650	14,920	15 unit	£150= $750	14,550	$\frac{11640}{746}=15.60$	£125= $625
30	22,380	17,904	18 unit	£165= $825	17,460	$\frac{13968}{746}=18.72$	£150= $750
35	26,110	20,888	21 unit	£180= $900	20,370	$\frac{16296}{746}=21.84$	£160= $800
40	29,840	23,872	24 unit	£200=$1,000	23,280	$\frac{18624}{746}=24.96$	£175= $875
50	37,300	29,840	30 unit	£250=$1,250	29,100	$\frac{23280}{746}=31.20$	£200=$1,000

The basis of the foregoing table is the fact that 1 effective horse-power put through a dynamo, a wire, and a motor, brings out .624 of an effective horse-power. This is equal to an efficiency of the whole of 62.4 per cent., which is quite a safe figure to work on, as some such systems when tested have yielded over 70 per cent. efficiency of the indicated horse-power.

COST OF SETS OF ACCUMULATOR CELLS TO SUIT VARIOUS TENSIONS.
(With approximate 60-Watt lamps easily maintained by them.)

No. of Plates.	Battery of 26 Cells for 50 Volts.			Battery of 32 Cells for 63 Volts.			Battery of 53 Cells for 100 Volts.		
	No. of Lamps.	Material of Box. Teak.	Material of Box. Glass.	No. of Lamps.	Material of Box. Teak.	Material of Box. Glass.	No. of Lamps.	Material of Box. Teak.	Material of Box. Glass.
7	10	£47 $235	£43 $215	13	£57 $185	£53 $265	21	£97 $485	£88 $440
11	18	£66 $330	£68 $340	22	£81 $405	£74 $370	36	£136 $680	£124 $620
15	25	£89 $445	£81 $405	30	£109 $545	£94 $495	50	£182 $910	£167 $835
23	38	£131 $655	£121 $605	46	£161 $805	£148 $740	76	£269 $1,345	£248 $1,240
31	50	£170 $850	£160 $800	60	£209 $1,045	£197 $985	100	£348 $1,740	£328 $1,640

The Settlement of the Number and Details of Accumulators.—The standard accumulators to be relied upon for general purposes of lighting and of driving motors, are those known as the L type.

These are made in 5 standard sizes, known by the number of plates they contain, 7, 11, 15, 23, or 31.

Naturally their capability for reception of current, and consequent amount of output, are in a similarly increasing ratio, their maxima being 13, 22, 33, 50, and 66 for 10 hours in each case. The pressure of the current being

made up by coupling accumulators one on to the other in succession, each may be taken at 2 volts, with a few additional cells to maintain the pressure as the discharging takes place.

We must thus have, either a set of 26 to get 50 volts,
or 32 " " 60 "
or 53 " " 100 "
or 106 " " 200 "

We thus find that any of these sets give us the following maximum work for 10 hours in electrical and in effective horse-powers for a motor of .80 efficiency.

Each Cell Containing	A Set of 26 giving 50 Volts.	A Set of 32 giving 60 Volts.
7 plates.	13 ampères × 50 = $\left\{\frac{650 \text{ Watts}}{746}\right\}$ = .696 Effective Horse-Power.	13 ampères × 60 = 780 Watts = 1.04 Effective Horse-Power.
11 "	22 ampères × 50 = 1,100 Watts = 1.2 Effective Horse-Power.	22 ampères × 60 = 1,320 Watts = 1.76 Effective Horse-Power.
15 "	33 ampères × 50 = 1,650 Watts = 1.76 Effective Horse-Power.	33 ampères × 60 = 1,980 Watts = 2.65 Effective Horse-Power.
23 "	50 ampères × 50 = 2,500 Watts = 2.68 Effective Horse-Power.	50 ampères × 60 = 3,000 Watts = 4 Effective Horse-Power.
31 "	66 ampères × 50 = 3,300 Watts = 3.52 Effective Horse-Power.	66 ampères × 60 = 3,960 Watts = 5.30 Effective Horse-Power.

Each Cell Containing	A Set of 53 giving 100 Volts.	A Set of 106 to get 200 Volts.
7 plates.	13 ampères × 100 = 1,300 Watts = 1.392 Effective Horse-Power.	13 ampères × 200 = 2,600 Watts = 2.784 Effective Horse-Power.
11 "	22 ampères × 100 = 2,200 Watts = 2.4 Effective Horse-Power.	22 ampères × 200 = 4,400 Watts = 4.8 Effective Horse-Power.
15 "	33 ampères × 100 = 3,300 Watts = 3.52 Effective Horse-Power.	33 ampères × 200 = 6,600 Watts = 7.04 Effective Horse-Power.
23 "	50 ampères × 100 = 5,000 Watts = 5.36 Effective Horse-Power.	50 ampères × 200 = 10,000 Watts = 10.72 Effective Horse-Power.
31 "	66 ampères × 100 = 6,600 Watts = 7.04 Effective Horse-Power.	66 ampères × 200 = 13,200 Watts = 14.08 Effective Horse-Power.

CHAPTER XXXV.

SHAFTING AND BELTING FOR TRANSMISSION OF POWER.

In a majority of cases, and from various causes, the operation of machinery by direct connection to the engine shaft is inadvisable. The engine requires to be exactly proportioned to the speed and duties of the one machine, which unfits it for any other duties. Therefore, the use of shafting to transmit power is unavoidable, and as it is a factor in deciding on the form of motor to be employed, it is here dealt with.

Heavy Shafting.—A very common error, and one that causes much waste of power, is the use of shafting that is unnecessarily heavy. It will probably astonish a great many mechanics to tell them it will require twice as much power to revolve a 4-inch shaft a given number of times per minute as it will a 2-inch shaft, even though the shaft be hollow and weigh no more than the 2-inch shaft. And it will probably surprise them still more to tell them that in the transmission of power a 4-inch shaft is eight times as strong as a 2-inch. It is true, nevertheless, all other things being equal.

The means of ascertaining the proper strength of an iron shaft is the following formula :

$$\text{The diameter should} = \frac{\sqrt{\text{The force applied in pounds} \times \text{the length of lever or crank applying it in inches}}}{1{,}700}.$$

In the case of a wheel applying the power, the length of the lever is obviously the half diameter of the wheel.

In the case of a mild-steel shaft, the diameter may be reduced, safely, ten per cent.

DIAMETER OF IRON SHAFTING PROPER FOR TRANSMITTING VARIOUS POWERS.

Revolutions per Minute.	Effective Horse-power Required to be Transmitted.									
	10	20	30	40	50	60	70	80	90	100
10	4.02	5.06	5.80	6.38	6.87	7.31	7.69	8.04	8.36	8.66
20	3.21	4.02	4.61	5.06	5.46	5.8	6.11	6.38	6.64	6.87
30	2.8	3.53	4.02	4.43	4.77	5.06	5.35	5.58	5.8	6.01
40	2.57	3.17	3.66	4.02	4.34	4.61	4.85	5.06	5.28	5.46
50	2.85	2.96	3.39	3.73	4.02	4.27	4.5	4.70	4.89	5.06
60	2.22	2.8	3.21	3.53	3.80	4.02	4.23	4.43	4.61	4.77
70	2.15	2.67	3.04	3.36	3.61	3.82	4.02	4.22	4.38	4.53
80	2.04	2.57	2.92	3.21	3.45	3.66	3.85	4.02	4.20	4.34
90	2.	2.46	2.80	3.07	3.33	3.53	3.71	3.87	4.02	4.18
100	1.86	2.35	2.69	2.96	3.17	3.39	3.56	3.73	3.87	4.02
120	1.76	2.22	2.57	2.8	3.03	3.21	3.36	3.53	3.66	3.80
150	1.64	2.08	2.35	2.62	2.80	2.96	3.14	3.27	3.39	3.53
170	1.58	2.	2.29	2.52	2.67	2.84	2.96	3.14	3.27	3.39
200	1.5	1.86	2.15	2.35	2.52	2.71	2.84	2.96	3.11	3.21
250	1.36	1.82	2.	2.22	2.35	2.52	2.62	2.75	2.88	2.96
300	1.29	1.62	1.91	2.08	2.22	2.35	2.52	2.62	2.71	2.80
350	1.26	1.59	1.82	2.	2.15	2.29	2.35	2.46	2.57	2.67
400	1.18	1.49	1.71	1.91	2.	2.15	2.29	2.35	2.46	2.57
500	1.08	1.44	1.59	1.83	1.91	2.	2.15	2.22	2.29	2.35

Belting.—In driving machinery by belting, a ready rule is 70 square feet of belt surface per second = 1 horse-power.

So that as the diameter of most engines' fly-wheels is stated with the price in manufacturers' lists, together with the revolutions, it is easy to take out the width of belt required to be driven off the fly-wheel.

Approximately

$$\left.\begin{array}{l}\text{The width of single}\\ \text{belting, say } \tfrac{3}{16} \text{ thick}\end{array}\right\} = \frac{1{,}100 \times \text{the effective horse-power.}}{\text{The velocity of belt in ft. per min.}}$$

A capitally arranged practical table, for which I am indebted to Mr. Charles L. Hett, A. M. I. C. E., is the following:

TABLE OF EFFECTIVE HORSE-POWER TRANSMITTED BY VARIOUS SHAFTS AND LEATHER BELTS.

ALL DIMENSIONS IN INCHES.

Diameter of a Shaft if well Supported.		1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5
Diameter of the Neck of a Shaft Carrying an Overhung Pulley.		1¼	1⅝	2	2¼	2½	2¾	3	3¼	3½	4	4⅜	4½	5	5⅝	6¼
Greatest Distance between Bearings		60	69	78	87	96	102	108	114	120	126	129	132	135	141	147
Effective Horse-Power to each Revolution.		.010	.019	.033	.053	.080	.114	.156	.208	.270	.343	.429	.527	.640	.860	1.25
Width of Suitable Leather Belting.		DIAMETER OF PULLEYS, ALL IN INCHES.														
Single.	Double.															
2	....	12	24	41	75	100	142									
3	....	8	16	27	43	66	95	130	170							
4	....	6	12	20	32	50	71	97	130							
5	....	5	10	16	26	40	57	78	104	134						
6	.... 4	4	8	14	22	33	48	65	87	112	143					
7	.... 5	......	7	12	18	28	40	56	74	96	122	153				
8	.... 5	......	6	10	16	25	36	49	65	84	107	134				
9	.... 6	......	......	9	14	22	32	43	53	77	95	119	146			
10	.... 7	......	......	8	13	20	28	39	50	67	85	107	132	160		
12	.... 8	......	......	......	11	17	26	30	43	56	72	89	110	133		
14	.... 10	......	......	......	......	14	20	28	37	48	61	76	93	114	154	
16	.... 10	......	......	......	......	......	18	25	32	42	54	67	82	100	135	
18	.... 12	......	......	......	......	......	......	21	29	38	48	60	73	88	119	
20	.... 14	......	......	......	......	......	......	......	26	34	43	53	66	80	108	156
22	.... 14	......	......	......	......	......	......	......	23	32	39	49	60	72	98	142
24	.... 16	......	......	......	......	......	......	......	......	28	36	45	55	66	90	130
	.... 18	......	......	......	......	......	......	......	......	24	33	41	50	60	82	119
	.... 20	......	......	......	......	......	......	......	......	33	30	37	45	54	74	108
	.... 22	......	......	......	......	......	......	......	......	......	27	33	40	49	67	97
	.... 24	......	......	......	......	......	......	......	......	......	24	30	36	44	60	86

Double Belting.—As a greater tension can be put upon double belts, the power transmitted by a given width is naturally greater, and a safe rule to assume is one-half more power than a single belt.

Ropes.—For driving machinery by hemp ropes, the circumference of the driving pulley must not be less than 30 times the circumference of the rope; a good proportion is 100 times.

(The circumference of any diameter = 3.141 × the diameter.)

The velocity of the rope should be from 3,000 minimum to 6,000 maximum lineal feet per minute.

For small powers the ropes should be 4¼ inches circumference. For large mill-driving the ropes should be 5¼ to 6½ inches circumference.

Weight of hemp ropes = The square of the circumference × .04 = lbs. per lineal foot.

Some ropes have run for over 10 years, but the average life of ropes is from 3 to 5 years.

V = velocity of ropes in lineal feet per minute.

$$\left.\begin{array}{l}\text{The circumfer-}\\\text{ence of the ropes}\end{array}\right\} = \frac{\sqrt{4{,}000} \times \text{the indicated horse-power}}{V \times \text{the number of ropes}}.$$

This being found out, add one extra rope as a spare, to allow for changing and repairs.

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